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ADVANCES IN THE ECONOMICS OF ENVIRONMENTAL RESOURCES
VOLUME 6

LIVING ON THE EDGE: ECONOMIC, INSTITUTIONAL AND MANAGEMENT PERSPECTIVES ON WILDFIRE HAZARD IN THE URBAN INTERFACE

AUSTIN TROY
ROGER G. KENNEDY
Editors

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CHAPTER 1

INTRODUCTION: FINDING SOLUTIONS TO THE URBAN–WILDLAND FIRE PROBLEM IN A CHANGING WORLD

Austin Troy and Roger G. Kennedy

As this introduction is being written, fire crews are racing with construction crews throughout fire-prone regions of the United States. Despite a national slowing of construction starts, the land rush into danger continues unabated – and the danger appears to be increasing. Records for the hottest and driest years are continuously being broken; the size and frequency of wildfires continue to increase annually; and the economic levers are still at work encouraging settlement where heat and tinder-dry vegetation are priming ever greater disasters.

While the 10 most fire-prone western states continue to receive far more than their proportionate share of population growth – nearly half that of the nation – fire hazards are not confined to that region. The rapidly growing state of Texas saw 1.45 million acres burned this summer, including 907,000 acres in the East Amarillo Complex. In the northern Great Plains states, generally not thought of as a hotbed of wildfire hazards, drought this year fueled the Cavity Lake fire which burned 39 square miles in Minnesota and was the region's largest fire in decades, as well as assorted grassland fires which burned 20,000 acres in North Dakota in just one month.

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According to the National Interagency Fire Center, the 2006 fire season is one of the worst on record. By late October 2006, it reported 86,454 fires, the largest number on record (since record keeping was started in 1960), and 9.442 million acres burned, compared to 71,682 fires and 5.311 million acres burned on average for the same period over the last 10 years. With several weeks left in the season, this year's season total has already surpassed last year's record of 8.689 million acres burned. Though there has been much press coverage, very little of it has dealt with the longer-term trends behind this record breaking. Notably ignored in the major press was the cover story of the late August edition of the journal *Science* in which Westerling, Hidalgo, Cayan, and Swetnam (2006) found that wildfire activity has increased significantly in the western U.S. over the last 30 years as conditions have become hotter and dryer. Wildfire seasons have become about two and a half months longer than they were in the period from 1970 to 1986. In a trend that became pronounced after the mid-1980s, they also found that longer lasting fire seasons were accompanied by a marked increase in the length of fires and their frequency. After 1986 wildfire frequency was found to be on average four times greater, and average area burned six times greater than for the period between 1970 and 1986.

The causes of these trends can roughly be broken down into four categories, each being the unintended consequence of some human activity: (1) global climate change, leading to longer, hotter, and dryer fire seasons; (2) national fire-suppression policies, leading to changes in vegetation structure and the buildup of fuel loads; (3) misguided or absent land use policies at all governmental levels, allowing development to occur unimpeded in some of the most hazardous lands; and (4) distortions in the hazard insurance market, leading to the underpricing of risk in the real estate market.

The first of these, the effect of global climate change upon fire duration and intensity, has not yet been fully felt, but needs to be understood. In Chapter 13 of this volume, William Keeton, Philip Mote, and Jerry Franklin assess the responses of wildfire activity to climatic oscillations over the past century and extrapolate from that relationship the probable behavior of fire in response to predicted changes in temperature and precipitation regimes of even greater magnitude in the future. They find that even small climate variations in the past have had considerable effects on wildfire activity; therefore, global climate change is likely to result in greater wildfire frequency and intensity in many regions of the western U.S. Analyzing more recent data, the study by Westerling et al. (2006), described above, provides evidence that this systematic change in wildfire behavior may already be occurring: increased fire frequency, intensity, and fire season duration over the last 20 years have been associated with higher temperatures, through mechanisms like earlier snowmelt and drought, which produce drying of fuels and greater opportunity for ignition. Their study does not attempt to answer whether these changes are the result of anthropogenically induced global warming, or merely the result of periodic natural fluctuations in temperature and climate, but there is no question that global climate change has the potential to make wildfire more dangerous and costly.

Further fueling these trends are the unintended consequences of two aspects of human land use: suppression policy and settlement policy. Dangerous feedbacks have developed between these two as suppression (discussed extensively by Kurt Menning in Chapter 5) has built up fuel loads while development policies and subsidies have led to more intensive human settlement in areas with these dangerous fuel loads, in turn encouraging further suppression. That is, the vast increase in settlement of humans in ecosystems adapted to fire has occurred as those ecosystems were made more dangerous to humans. These two processes evolved independently – fire suppression from 1890 onward and subsidized dispersion through promiscuous grants and guarantees by governmental units from 1947 onward. This process of dispersion and its interaction with suppression is described by Roger Kennedy in Chapter 2 of this volume as well as other studies (Covington & Moore 1994; Moore, Covington, & Fule, 1999; Schoennagel, Veblen, & Romme, 2004).

As more people settled in fire-prone ecosystems, and there were more suppression activities to protect their property in the short term, they and their property became increasingly imperiled in the long term. Fuels that otherwise might have been purged through smaller, cleansing fires were permitted to accumulate, and prescriptive and controlled burning was inhibited by public opposition due to incomprehension of its necessity (a phenomenon extensively analyzed by Menning in Chapter 5). In the case of forest ecosystems, suppression built up so-called "ladder fuels" facilitating upward sweeping of brush and grass fires to become canopy fires. That effect made especially dangerous the semiarid ponderosa pine ecosystems of the nation's interior, which are delightful when not burning, and therefore have received many "amenity migrants." This ecosystem, previously characterized by frequent and relatively small fires has, through suppression, become characterized by denser stands and high-severity fires (Schoennagel et al., 2004). Not surprisingly, the rapidly growing populations of counties within that system have suffered from some of the most destructive wildfires in recent history, such as the 2002 Rodeo–Chedisksi fire complex and Hayman fire.

Strategies for dealing with the wildfire problem fall into three general categories: attempts to manage fire itself, vegetation, and communities.

"Fire management" refers to the suppression and combating of large fires; its processes, techniques, institutions, and devices are described in detail by smokejumpers Ben Machin and Mark Hentze in Chapter 12. While new information, communication, and transport technologies have greatly increased the reach and efficiency of fire crews in suppression efforts, this success is allowing for greater fuel buildup, inadvertently making those fire crews ever busier. Kennedy's Chapter 2, Menning's Chapter 5, and other studies such as Franklin and Agee's (2003) describe the evolution of fire suppression as the approach favored in the United States, and the consequences of this strategy.

Recognizing the inadequacies of a pure suppression strategy, fire managers and national policy have increasingly embraced fuels management strategies, including prescribed burning (one might well call it "pre-burning"), mechanical treatments (sometimes called "thinning"), and "wildland fire use" in which wildland fire crews strategically allow remote wildland fires to burn themselves out, as described by Machin and Hentze in Chapter 12. Thinning was urged forward by the passage of the 2002 Healthy Forests Restoration Act (HFRA), authorizing $760 million a year to thin forests on federal lands, 50% of which was to be spent near the edges of existing development in the so-called "urban–wildland interface" (UWI). The emphasis upon UWI areas for directing fuel treatments was reinforced in the recently released federal *Cohesive Fuels Treatment Strategy* (USDA Forest Service & U.S. Department of the Interior, 2006). Prescribed burning to reduce fuels has become almost universally recognized as desirable except by many of those who actually experience it in their neighborhoods and must deal with its smoke, noise, and risk of becoming out of control. Some may also dislike the fact that such treatments make danger apparent rather than merely inherent. Prescribed burning's potential and the obstacles to its implementation are described in Chapter 5 by Kurt Menning. Other frequently employed UWI vegetation management methods include maintenance of fuel breaks, defensible space around structures, and defensible fuel profile zones, all described by Scott Stephens and Brandon Collins in Chapter 3.

Traditionally, vegetation management for fire hazard mitigation has been conducted by public agencies on public land. However, as local ordinances increasingly require homeowners to use such means to reduce the fire hazard on private residential land (as experience shows how fire spreads from the property of one neighbor to another), the distinction between "vegetation management" and "community management" for fire hazard mitigation is becoming increasingly blurred.

Because vegetation management is a never-ending job that often must occur in or near people's backyards, it needs to be carried out at the community level by citizens acting together. Therefore, fire management often becomes people management. In Chapter 9 by David Ganz et al. there is a detailed discussion of how communities have organized themselves to undertake wildfire management and how a variety of institutional approaches have developed to facilitate community-based planning. A prominent example is the California Fire Safe Councils. Chapter 10 by Stokowski discusses the academic literature's perspectives on the factors behind successful community action for wildfire planning and management.

Fuels management is promising, but it is insufficient on its own to address the problem of increasing wildfire hazard, particularly in the UWI. Extreme climate conditions, such as those that could be associated with global climate change, will likely diminish the benefits and effectiveness of fuels treatments. Though Schoennagel et al. (2004) found that fuels treatment can affect the spread of fires, their effects may not be sufficient to halt wildfires. For instance, they found that in the case of the Hayman fire in Colorado many areas burned where fuels had been previously treated, largely because of preceding drought conditions, a conclusion shared by the USDA Forest Service General Technical Report on the Hayman fire (Finney, 2003). Without treatment, of course, the consequences might have been far worse. But without the rapid growth of population in the five affected counties, the resulting dollar losses would have been far less.

Concerted self-management at the community level offers promise where large-scale coordinated vegetation management might be inadequate or infeasible. Already many communities are "engineering the landscape" around and between structures, cutting and sustaining firebreaks and defensible space, using and requiring "firewise" structural materials that make property less flammable, developing more sophisticated disaster plans, and educating residents. As Chapter 4 by Robert Paterson describes, a large number of communities and states are beginning to integrate such "Safe Smart Growth" strategies into their planning and zoning in order to mitigate wildfire hazard and create more sustainable communities, in some cases under requirements from state government.

Another approach is to harness the "free market" which, although heavily warped by federal and state subsidies, can potentially be restored to something somewhat freer by more accurate pricing of risk. Market-enhancing mechanisms, such as insurance and disclosure, can help internalize some of the social costs of fire zone development and result in more efficient land use patterns. As Chapter 7 by Candysse Miller points out, the insurance underwriting process that underlies premiums and determines availability has become increasingly sophisticated, factoring in not only wildfire risk, but also community actions to mitigate that risk. The use of geographic information ystem (GIS) and fire-modeling technology (such as that discussed by John Radke in Chapter 11) can quantify relative fire risk which can, in turn, help with disclosure and insurance pricing. When insurance premiums charged by the open market reflect actual risk, the market will operate to encourage safer growth. In this way, a freely functioning, straightforward, and candid market for both insurance and real estate can help guide development away from hazardous land. However, as Chapter 8 by Troy demonstrates, unintended consequences to well-intentioned policies have flourished in this domain. In California, as in many other states, the Fair Access to Insurance Requirements (FAIR) Plan, an insurer of last resort, provides below market rate insurance to home buyers in areas that are so hazardous that the private market no longer will cover them. While FAIR Plan policies provide only a limited amount of coverage, a significant number of homeowners rely on them entirely. FAIR Plans essentially require private companies to write policies below cost, providing a subsidy to wildfire zone policyholders at the expense of ratepayers in general. A freely functioning insurance market should guide development away from hazardous areas, or areas with poor mitigation, because premiums paid by homeowners would reflect risk. But governmentally introduced "insurers of last resort" like FAIR Plan distort this pricing mechanism by providing an artificially low-priced alternative that bypasses the market, thereby subsidizing settlement in hazardous areas.

Mandatory disclosure – candor or truth about risk – can work in combination with true and undistorted risk assessment in insurance to create a relatively free market for safe, as well as smart, growth. Mandating better information about the costs associated with living in hazardous areas will permit wiser decision-making. People will be less willing to pay to live in them. This reduction in demand should signal developers to build less in hazardous areas, or to better mitigate risks when they do. While flood hazard disclosure has been found to have significant effects on property markets (Troy & Romm, 2004), as these authors point out in Chapter 6, fire disclosure in California appears to have had no negative effect on property markets, except in areas near where a recent major fire occurred. In fact, not so strangely, fire zones are actually associated with higher home prices, probably because so many home buyers value the scenic amenities of these combustible areas. When prospective homebuyers do not know the risks thereby assumed, they are of course more willing to do so. Since we have little experience with patterns of decision making in the presence of full risk-pricing and full risk-disclosure, it is not strange that we do not know how much risk residents will be willing to trade off for each level of amenity. Buyers may not really appreciate what kind of insurance they can get, how much it will cost, and how severe the fire hazard is in their neighborhood. This last point is an important one because, as Chapter 8 points out, even in California, where statewide fire policy is far more sophisticated than in most other states, currently available "disclosure" maps simply have only a binary designation – hazard zone or no-hazard zone – rather than a graded system like the one that governs premium setting by the insurance industry. Therefore, buyers have little conception of the actual risk facing them. Chapter 8 also points out that California's fire zone maps are inaccurate, because, through a loophole in the laws enabling them, local jurisdictions can opt out of having land within their boundaries designated, even if they are hazardous, and many have taken this path. After all, what local government wants to build a billboard declaring "We Live in a Hazardous Fire Zone"?

These market mechanisms can certainly be improved. Reforming insurers of last resort so they do not cover new development and creating a better mapping and disclosure system could go a long way toward facilitating smarter development patterns. Sophisticated computer modeling tools, such as those described by Radke in Chapter 11, are already being used by insurers to better price risk for market-rate policies. Use of computer models to produce graded risk maps would produce more effective disclosure.

Whatever promising approaches may be followed at the local and state levels to manage fuels, design fire-smart landscapes and buildings, improve insurance and disclosure, and diminish the impact of wildfire when it comes, the broader problems remain: ever accumulating fuels, hotter and dryer temperatures, and more and more people in fire-endangered places. If fuels treatments and market mechanisms are not complete answers in the face of population pressure and global climate change, what can be done? Once again, the answer is that fire management becomes people management.

No people management approach is more effective in mitigating fire hazard than guiding development away from hazardous areas. However, two factors complicate this. The first is the system of public subsidies that unintentionally facilitates settlement in hazardous areas, including federal mortgage insurance and transportation and utility infrastructure. The second is the framework of land use regulation in the United States. Unlike in many other countries, land use regulation in the U.S. is largely devolved to municipal and county governments, of which there are nearly 22,000. Many roadblocks exist to coordinating firewise land use management at a regional or higher level. Such efforts frequently meet with angry opposition from both private property interests and the jurisdictions themselves, not only because of financial self-interest, but also because of a culture of local control. While many jurisdictions are doing the right thing, in aggregate they are uncoordinated. Most jurisdictions have little incentive to call attention to hazards or to limit private property rights because state and federal governments pay for most disaster recovery while municipal and county governments reap the benefits of development (Burby, 1991). Further, municipalities that zone out development in hazard zones do so at the expense of their tax base while, simultaneously, neighboring jurisdictions may be financially benefiting by opening up their hazardous lands to development. For these reasons, local governments are unlikely to engage in any form of land use planning for hazard mitigation absent a state or federal mandate (Burby & Dalton, 1994; Burby, 1991). In fact, surveys in the past found that concern for natural disasters among local officials ranked very low among the many concerns of local officials, below air pollution and pornography (Rossi, Wright, & Weber, 1982). However, the apparent increasing interest in ''safe smart growth'' planning approaches among local officials, as described by Paterson in Chapter 3, suggests that times may have changed.

Without doubt, federal and state governments have the greatest potential to effectively implement firewise planning over large areas. While it is common wisdom to believe that land use planning is only a local matter in the United States, in fact federal and state governments have a far more historically legitimated legacy of regulating land use – particularly where it relates to planning for natural hazards – than is commonly recognized. There has been a long history of federal and state land use regulation in the United States – even before the Northwest Ordinance decreed that slave-driving plantation agriculture would not be encouraged north of the Ohio River. The federal government has reserved vast areas for bases, forts, lighthouses, and military training – the maps of California and Florida would look quite differently otherwise. National Monuments occupy millions of acres, and National Parks reserve from mining and grazing vast areas – and not just in the West. The national and state forest systems are all manifestations of land-use regulations.

Federal and state intervention into land use for the purposes of hazard reduction goes back over a century. Starting in the 1860s states such as Wisconsin began withdrawing cut-over fire-prone land from settlement. After a series of great fires over a century ago, including one that burned 480 square miles in 1894, Minnesota worked with the federal government to set aside nearly a third of its land for fire protection. Included in this was the

Chippewa National Forest, the first Congressionally mandated forest reserve, created in 1902. One of the biggest motivations that then State Fire Warden (and later State Forestry Commissioner) Gen. Christopher Columbus Andrews had in requesting that this acreage be set aside was the management of fire hazard – both a desire to restrict settlement on hazardous land and to keep unsustainable forestry operations from making that land more prone to fires. Under the Weeks Act of 1911, other states were encouraged to follow the Wisconsin example – Minnesota had followed suit in the aftermath of the great fires of the 1880s and 1890s.

Perhaps the prime example of federal intervention in regulation of hazardous lands stems back to the late 1960s, with the National Flood Insurance Act. In response to the rising cost of flood disaster assistance, the unavailability of private flood insurance following several major floods, and the lack of action on the part of local governments to mitigate flood hazards, the federal government was given some regulatory oversight of development in designated flood zones. The National Flood Insurance Program (NFIP), initiated in 1968 under the National Flood Insurance Act, dictates that for homeowners in a jurisdiction to be eligible for federal flood insurance, and hence predictable compensation after a flood, they must enforce, at a minimum, flood-safe building codes in floodplains. Further, it requires that all properties in designated flood zones pay into the flood disaster relief system through mandatory purchase of federal flood insurance. While it stops far short of zoning out development or reducing densities in high-hazard areas, the NFIP at least demonstrates that the federal government has the proven authority to regulate private land where mitigation of hazards is concerned.

It is also an indication that private property rights have limits when greater issues of social good are at stake. The law of what can be done by private landowners on their own land is grounded in feudal practice, and the fact that nearly all land titles in the United States arise from devolutions from the sovereign – the sovereign nation in most cases – which under the common law carry requirements and obligations. Judicial precedent clearly articulates that there is no such thing as a right to conduct oneself on one's own property in a manner that puts one's neighbor at risk. When wild fire spreads, it knows no title deeds.

Why, then, are state and federal governments not more involved in managing the most-flammable lands? While the lack of federal or state programs to regulate land use in fire hazard zones most likely relates to the smaller scale of potential property damage from fire relative to floods, it is also probably due to the fact that fire-zone regulation would serve to regulate vast amounts of private property, a sure political loser in a country that has been so strongly shaped by a culture of private property rights. Because fire-driven ecosystems are where so much new growth is happening, from the Coast Range to the Front Range, any attempt to try to curtail growth in fire hazard zones is almost certain to fail until land use regulatory paradigms significantly change. Yet, as this book shows, even if we cannot keep settlement out of hazardous lands in the short term, there are still promising alternative approaches at our disposal to foster a more peaceful and sustainable coexistence between fire-driven landscapes and the communities that inhabit them.

BOOK SUMMARY

This book is divided into four parts: (1) Institutions and policy, (2) The economics of hazards, (3) Community involvement, and (4) Management and ecology. The first section contains four chapters that cover the issue of wildfire from historical and institutional perspectives. "Forest fire history: learning from disaster" by Roger Kennedy (Chapter 2) addresses the pressures and politics giving rise to the current situation. "Fire Policy in the Urban–Wildland Interface in the United States: What are the Issues and Possible Solutions?" (Chapter 3) by Scott Stephens and Brandon Collins provides a summary of the problems associated with wildfire hazards in UWI communities, discusses fuels-treatment options for local governments and property owners, and analyzes challenges to planning, drawing on experiences from Australia. "Wildfire hazard mitigation as "safe" smart growth" (Chapter 4) by Robert Paterson looks at how smart growth principals are being adapted to fire-safe land use planning and zoning, including a discussion of the role of regional coordination and state-level planning requirements. "Practical and institutional constraints on adopting wide-scale prescribed burning: lessons from the mountains of California" (Chapter 5) by Kurt Menning details the problems of fuel accumulation due to suppression, the potential power of prescribed burning as a management tool, and the social and regulatory obstacles to implementing wide-scale prescribed burning programs.

The second section looks at the role of the market. "The effects of wildfire disclosure and occurrence on property markets in California" (Chapter 6) by Austin Troy and Jeff Romm is an econometric analysis of property data relevant to mandated fire zone disclosure under a recent California law, and shows how that law has affected property values and how the price effect is conditional upon the occurrence of recent nearby fires. "Wildfire underwriting in California: an industry perspective" (Chapter 7) by Candysse Miller offers her perspective, as Executive Director of the Insurance Information Network of California, on wildfire in urbanized areas. It explains the underwriting of fire insurance works and how the industry is changing its practices to more accurately price premiums based on objective risk and community mitigation efforts. "A tale of two policies: California programs that unintentionally promote development in wildland fire hazard zones" (Chapter 8) by Austin Troy focuses first on the FAIR Plan (described above) and how it distorts the pricing of risk in the California insurance market. It next looks at mapping of Very High Fire Hazard Severity Zones for disclosure and fire zoning purposes, and how political loopholes have compromised the reliability of this mapping effort.

The next section examines the means by which communities confront wildfire hazard through planning, mitigation, and recovery. "Community involvement in wildfire hazard mitigation and management: Community Based Fire Management, Fire Safe Councils and Community Wildfire Protection Plans" (Chapter 9) by David Ganz, Austin Troy, and David Saah, is a chapter devoted to models of community involvement in wildfire planning, from southeast Asia to the California suburbs. It suggests ways to evaluate participation, effectiveness, and outcomes focusing on several case studies such as the California Fire Safe Councils. "Human communities and wildfires: a review of research literature and issues" (Chapter 10) by Patricia Stokowksi reviews the academic literature on community involvement in wildfire planning. She offers varying definitions of "community" in this context, and discusses the role of formal and informal institutions, social ties, outside organizations, communication mechanisms, and outreach programs in the planning process and post-fire recovery efforts.

The final section deals with technical and ecological aspects of fire management. "Modeling fire in the wildland–urban interface: directions for planning" (Chapter 11) by John Radke describes a GIS-based computer model that was built to assess hazard in the Oakland/Berkeley East Bay Hills, site of the catastrophic 1991 Tunnel Fire. In addition to describing the model, Radke addresses some of the data challenges involved in fire-modeling efforts. "Comments on the present and future of wildland fire suppression decision-making processes" (Chapter 12) by Ben Machin and Mark Hentze describes how large fires are fought. It details the extremely complex process of detecting fires and incident management both from the authors' perspective as people who fight them, and from an institutional perspective. It further describes some of the promising new technologies that may help in this effort. Finally, "Climate variability, climate change, and western wildfire with implications for the urban–wildland interface," (Chapter 13) by William Keeton, Phillip Mote, and Jerry Franklin addresses the potential relation between global warming and increased fire activity. Looking at historic data, they find that fire activity increased in years with hotter and drier climate conditions, suggesting that future warming can be expected to lead to more fires. They conclude with a discussion of how communities and land managers in UWI areas can prepare for these new conditions.

While this book offers a variety of viewpoints upon some of the most pressing questions now being debated with regard to wildfire in the UWI, it does not strive for encyclopedic completeness, or for parliamentary representation of all points of view. Instead it opens a window into a vast literature, and provides an introduction to the writings of some of the most innovative researchers and practitioners now at work in the field.

REFERENCES

Burby, R. J. (1991). *Sharing environmental risks: How to control governments' losses in natural disasters*. Boulder, CO: Westview Press.

Burby, R., & Dalton, L. (1994). Plans can matter – The role of land use plans and state planning mandates in limiting development of hazardous areas. *Public Administration Review*, *54*, 229–238.

Covington, W., & Moore, M. (1994). Southwestern ponderosa forest structure – changes since Euro-American settlement. *Journal of Forestry*, *92*, 39–47.

Finney, M. (2003). Fire behavior, fuel treatments, and fire suppression on the Hayman fire. In: R. Graham (Ed.), *Hayman fire case study analysis* (pp. 59–96). Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Franklin, J., & Agee, J. (2003). Forging a science-based national forest fire policy. *Issues in Science and Technology*, *20*, 59–66.

Moore, M., Covington, W., & Fule, P. (1999). Reference conditions and ecological restoration: A southwestern ponderosa pine perspective. *Ecological Applications*, *9*, 1266–1277.

Rossi, P. H., Wright, J. D., & Weber, E. (1982). *Natural hazards and public choice: The state and local politics of hazard mitigation*. New York: Academic Press.

Schoennagel, T., Veblen, T., & Romme, W. (2004). The interaction of fire, fuels, and climate across rocky mountain forests. *Bioscience*, *54*, 661–676.

Troy, A., & Romm, J. (2004). Assessing the price effects of flood hazard disclosure under the California natural hazard disclosure law (AB 1195). *Journal of Environmental Planning and Management*, *47*, 137–162.

USDA Forest Service, & U.S. Department of the Interior. (2006). Protecting people and natural resoures: A cohesive fuels treatement strategy. pp. 60.

Westerling, A., Hidalgo, H., Cayan, D., & Swetnam, T. (2006). Warming and earlier spring increase western US forest wildfire activity. *Science*, *313*, 940–943.

PART I:
INSTITUTIONS AND POLICY

CHAPTER 2

FOREST FIRE HISTORY: LEARNING FROM DISASTER☆

Roger G. Kennedy

ABSTRACT

Recent hurricanes, dust storms, and wild fires have presented great learning opportunities that have largely been missed, yet still may stimulate improvements in currently dominant policies driving settlement of large numbers of Americans into places exposed to fire, dust, and flood. Equivalent opportunities led to large and beneficial alterations in policy during the administrations of Presidents Hayes, Harrison, Theodore Roosevelt, Taft, Franklin Roosevelt, and Eisenhower, when changes sprang from recognition that federal subsidy programs and land allocations channel settlement. Induced by public policies acting like magnets under the tables of their lives, millions of Americans, like iron filings, have been migrating into increasing peril of fire and flood; it is not only possible to slow this down, but even to encourage settlement away from areas recurrently subject to natural disaster. Tax-payer subsidies, systematically contrived in the Cold War period to disperse the older industrial centers lest they be readily obliterated by Soviet nuclear weapons, are still in place, though

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the Cold War has thawed, and the world now presents challenges toward which Cold War policy is not only inept but making matters worse.

It is expensive to rescue people. The costs of rescue are born by taxpayers, who have no role in choices by the people rescued to live in hazardous places. It is also expensive to subsidize movement into places from which it is likely that they must be rescued. And it is an affront to civic morality for people to be induced by implicit assurances arising from subsidies to accept risks unknown to them. Taken together, federal tax support of dispersion strategies developed in the 1950s and sustained into 2006 have so far exceeded a trillion dollars and are rising. The GI Bill alone channeled more than $600 billion in mortgage financing, most of it outside traditional urban and village centers into the countryside, to the benefit not only of home owners but also of a dispersion-industrial complex, as important as the military-industrial complex.[1]

In recent years a fire-industrial complex has also emerged to do a billion and a half in annual business in fire-disaster relief and repair, highly predictable "emergency" contractual work contracted without much scrutiny, year after year. This method of disaster relief is made necessary because there are people being hurt. Their presence in the path of wild fires is no accident, though it is often a disaster. During the Cold War and afterward, federal policy accelerated and multiplied dispersal of population out of older cities into newer and less concentrated urban centers and into what was previously countryside. These policies were formed in disregard of the civic continuities of such older cities or of the villages into which the dispersed flowed, and also with little regard for the biological consequences to the ecosystems affected by new occupation.[2]

Opposing this form of deliberate dispersal has been an anti-sprawl movement, sustaining into the present – though not always consciously – a long history of previous efforts to channel internal migrations away from extremely dangerous places. Some of those dangers have been military – as in the instances of "pioneers" being discouraged from invading Indian reservations and the endeavor of President George Washington to diminish private invasions of the Spanish dominions. Others redemptive actions have recognized natural limits to safe habitation, as the American people learned from dust, flood, and wildfire how to diminish the pace of a land rush into danger. They can learn again.[3]

On both sides of the Wildland/Urban interface systems, the problems of fire and flood are not with fire or flood but with people in the presence of fire and flood. The word ''disaster'' belongs to history, not to natural history. It denotes a large event causing damage to humans. Disasters do not occur in wilderness, in arctic expanses, or in deserted seas where no ships venture. No humans – no disasters. The greater the number of humans, the greater the disaster arising from fire, flood, dust, volcanic eruption, earthquake, and hurricane. And the prospect of disaster increases when the severity of natural events befalling people increases, a high probability during global climate change.

Noted below are many elements of the panoply of government subsidies asserted after the Second World War that had the effect of accelerating the pace of migration into flame zones where more and larger wild fires are likely. As shown in Table 1, this national migration into fire danger has been from the American Heartland in the Midwest and Great Plains upward to the flanks of the mountainous West, and to a secondary degree to the currently salubrious – but warming – Southeast.

Meanwhile, within each state, local (or metropolitan) migrations have been outward from the old industrial and trading cities into the suburbs, into exurbia, and increasing wild fire danger.[4]

There has been nothing covert in the expenditures encouraging these outcomes. Public power in the West has been largely federally financed power generation and distribution, which has been made available on

Table 1. Seven States Ranked by Population Growth and Aridity.

State	Ranking in population growth[a]	Ranking in exposure to fire[b]	Annual rainfall (inches)[c]
Nevada	1	1	9.46
Arizona	2	4	13.10
Utah	4	2	11.88
Colorado	5	7	15.47
Idaho	8	9	19.02
New Mexico	10	5	13.85
Wyoming	19	3	12.69

Note: Rank 1 is the highest.
[a]Census data contrast U.S. Bureau of the Census Reports for each decade from 1950 through 2000. Between 2000 and 2006 Colorado slipped a little in its position, but the other relationships were sustained. See Census of 2000 as updated by the bureau of the Census on its website
[b]As simplified to record only annual rainfall in inches; dryness is important, though so is the availability of fuel.
[c]Rainfall statistics state by state can be found in any standard encyclopedia.

demand, without regard to the effects of availability upon the location of settlement. The administration of more than a trillion dollars in Federal mortgage insurance has favored suburban and exurban growth, especially in the West. Federal fire fighting and rescue operations have assured in-migrants to flame zones that they will receive help from other taxpayers when fire returns to flame zones. The expenditure of post-fire funds to pay private contractors to do "emergency" (but recurring) post-fire pickup has run at an average exceeding a billion and a quarter dollars a year. The taxpayers pay to produce the problem and pay again to cope with its aftermath.[5]

In fire zones, wildfire is a part of the natural life. Plants grow and dry out. True, humans have contributed to the severity of the wild fire problem both by their presence and by inducing over grazing by eliminating natural grasses, which burn less ferociously than the brush and small trees that have replaced them. Fire suppression still alters these conditions to make them more dangerous, as it has since Europeans first arrived. It became official U.S. Government policy in the 1920s and increased perils to human life because fuel loads accumulated as small, natural fires were extinguished, and in many places, despite changes in official policy, fire is still suppressed.[6]

Yet the greatest cause of disaster remains the presence of people induced to enter perilous places. Cold war policies, only recently apprehended in their full magnitude and subtlety, followed recommendations set forth repeatedly in essays in the *Bulletin of the Atomic Scientists* after an initial essay by Edward Teller, E.M. Marshak of the University of Chicago, and Lawrence R. Klein, later Nobel Laureate for Economics. The drumbeat was taken up in a multitude of government reports and Congressional action in the Cold War years. These policies were also carried forward in detail by two large-scale projects, Project Charles and Project East River, whose activities appear in massive reports (I am told) filling 18 (classified) volumes.[7]

The programs ensuing were anticipated early in the process by two Detroit city planners, Donald Monson and Astrid Monson, stating their objective to be accelerating the "breaking up the central mass of a large city" to make the old industrial cities less vulnerable to Soviet attack. Since the automobile was rendering "the distance from the center of town … relatively unimportant," the government should initiate "a program of planned dispersal … speeding up construction of broad express highways through our large cities." Dense old cities should "receive no additional defense work in order … [to] induce workers to transfer to less hazardous areas." The Monsons went on with the other portions of the prescription.

> FHA mortgage and GI insurance would be granted only to housing built in accordance with the plan [of dispersal].
>
> FHA public housing would be built only in accordance with the plan, [with priority to those] displaced from slum or other central city areas being cleared.
>
> Federal slum clearance loans and grants would be given only … [when] fitted into the dispersal plan – i.e., … reduced the density of an overcrowded area.
>
> RFC and other government loans would be made only to industries locating in areas designated by the plan …
>
> Defense contracts, materials, allocations. Tax concessions and other inducements would be given to firms locating new plants … with special encouragement [to relocate] to firms now located in areas within the central city designated for clearance …
>
> Federal aid for highway construction and other public works would be granted only for projects essential in carrying out the dispersal plan and would be stepped up in order to speed the rate of their completion.
>
> Other aids to cities would be conditional on their implementing the dispersal plan by amending and enforcing zoning regulations, refusing building permits for new construction … etc.
>
> Land … within the central city … cleared … and not rebuilt, such as strips bordering on expressways … can serve as separation strips buffering off one community from another … such slum areas as are not to be rebuilt … [They] will form … firebreaks … [S]lum clearance should be speeded up…breaking up the central mass of the city … as rapidly … as possible. (Monson & Monson, 1951, p. 245 ff)

Fifty years later, American taxpayers continue to subsidize and therefore encourage more and more of their fellow citizens to suffer and die. In many of their destinations, dangers have been increased by overgrazing, reckless lumbering, and improvident plowing. That has been the past. Still, however, migration into flame and flood zones continues, rescuers are still dying, life savings are still going up in the smoke or drifting downstream on the waters of floods. The future includes global climate change; in all probability it will bring higher sea levels, more hurricanes and floods, and more wild fires (see Chapter 13 by Keeton et al. for more discussion of the ramifications of global climate change) by extending dry and hot areas. Manifestly, new policies at the local, state, and federal levels are imperative. Fortunately we need not go forward blindfolded. There are good precedents for remedial action.

THE AMERICAN TRADITION OF CORRECTING BAD POLICY: WHEN IT IS APPARENT HOW BAD IT HAS BEEN

Since 1787, the Congress has encouraged some settlement patterns – and with them uses of the land – and discouraged others. One of its first pieces of legislation was to reaffirm the Northwest Ordinance, adopted before the Constitution was adopted. The Ordinance encouraged smart growth, meaning intentional allocation of land and resources to induce beneficial settlement, and it discouraged deleterious land use by battalions of slaves. Thereafter, federal transportation policies induced some settlements and discouraged others. Turnpike construction and land grants following recommendation on the part of Secretary of the Treasury Alexander Hamilton were made more systematic by Thomas Jefferson's Treasury Secretary, Albert Gallatin. Gallatin's system of National Roads anticipated the Age of Steam, though his subsidies seem meager in comparison to those of the Age of Steam, when four times as much land was provided from the national commons to subsidize railroad construction as now lies within all the National Parks outside Alaska. The Homestead Act was a land-use subsidy, as the plantation owners asserted in blocking its enactment for a decade before 1862. These policies were the direct predecessors of the Federal Highway Programs of the 1930s and afterward of the Intermodal Surface Transportation Efficiency Act of 1991.[8]

The central tenet of this tradition is that the nation's taxpayers have a stake in the ways in which their money is spent and the nation's land legacy is used. Accordingly, some kinds of settlement and growth have been encouraged and others discouraged. There have been many instances of a more direct redemption of fire, dust, or flood ravaged areas through their being relieved of settlement, and settlers being relieved of the dangers of such settlement. The Federal park and forest systems ensued after the "natural disasters" of the period from 1885 through the great fires of 1910–1911, as responses both to "natural" disasters and unnatural settlement patterns.

Over 200 years of experience with wild fire make plain the lesson that people will die unless lumbering is done with very great care and at a safe distance from towns. Killer fires have broken out on cutover land. Death, pain, and loss had come upon those who rushed into the sawdust and stumpage, unaware of its dangers. That great lesson of fire was learned in Vermont before 1810 by George Perkins Marsh, the first American to write systematically about fire, the limits of settlement, and the need for forest restoration. Marsh provided the theoretical basis for private restoration and also for public participation in sustainable forestry. His ideas gained further impetus from the experience in Wisconsin of Carl Schurz, who, as Secretary of the Interior, saved Yellowstone National Park from lumbering, founded the United States Geological Survey, and set the course of action that led to the creation of a fully professional National Forest Service, using science as its guide.

Wisconsin took land out of settlement, helping farmers who had tried to make a go of living in the burnt-over lands to find homes elsewhere. Legislation was passed for countywide zoning, a good idea for Wisconsin in 1924 and a good idea for Arizona in 2004. Wisconsin's constitution was amended to clear away a decision by its Supreme Court made in excessive deference to a ‘‘need to log’’ everywhere, and creating instead ‘‘fire protection districts’’ where further logging was undesirable. Wisconsin's most distinguished historian of the politics of fire and settlement concluded that establishing fire protection districts – which in these pages have been called ‘‘flame zones’’ – ‘‘was a final recognition, that an unsuccessful farmer, settled on unsuitable land in an isolated place was anything but a taxable asset to the county.’’ Promiscuous lumbering had only created ‘‘charred, cutover land … when the forest was gone and nothing was left to hold the soil in place … banks severely eroded by increased rainwater runoff and from log drives. Many lakes … [were] so filled with silt that they became more like swamps and muskegs. Alder took root where once there had been blue water.’’ (McMahon & Karamanski, 2002, p. 12 of Chapter 4 [www.nps.gov/archive/sacn/hrs/hrs4l.htm].)

After the state constitution of Wisconsin was amended to permit the legislature to establish ‘‘fire protection districts,’’ or ‘‘flame zones,’’ that action was said by the state's premier forest historian to be the ‘‘final recognition, that an unsuccessful farmer, settled on unsuitable land in an isolated place was anything but a taxable asset to the county’’ (Nesbit, 1973, pp. 470–471).

The Forest Crop Law of 1927 put into Wisconsin state law the principal first enunciated by George Perkins Marsh that modest governmental encouragement would be enough to change the crossover point between the economics of farming and timber culture. Counties dedicating tax-forfeited agricultural land to reforestation, and removing it from their tax rolls, could receive state subsidies in return. Two years later, counties were authorized to implement countywide zoning to ‘‘encourage cutover settlers to move closer together instead of farming in isolation’’(Gough, 1991, pp. 11–14, 15–19).

The homestead taken up by Carl Schurz in Watertown, Wisconsin is situated northeast of Madison on the frontier between the grassland and the forest. Sun Prairie lies just to the east and the timbered Baraboo Hills just to the west, much of them covered with trees dependent upon regular fires to reproduce properly. The great white pines of the sand plains reared up against the skies a little farther to the north, where in the 1840s it was said at the time that the sound of the woodman's axe had never been heard in the pinelands about the headwaters of the St. Croix and Chippewa Rivers.

By 1900, lumbermen had left those streams full of brush and slash, and federal migration policy, laid out in the Homestead, Desert Lands, and Timber Culture Acts, had induced settlers to ruin their lives trying to make farms in the cutover. Wisconsin had already suffered so much from forest fires where the timbering had left the countryside strewn with branches and sawdust that in 1867 that its Forest Commission had issued a report entitled, *Report of the Disastrous Effects of the Destruction of Forest Trees Now Going on So Rapidly in the State of Wisconsin*. In October 1871, nearly four million acres, thousands of homesteads, and five towns were burnt in the northeast corner of the state and upper Michigan, less than a hundred miles from Schurz's home. Fifteen hundred people were killed, five times as many as in the Great Chicago Fire of that year. The fire is known in the annals of the Midwest as the Great Peshtigo Fire, and remembered as the consequence of both promiscuous lumbering and the failure of lumber-carrying railroads to remove the fire load produced when they cut their way into the woods. The death toll would have been much worse had fleeing settlers not been able to find refuge in two rivers and Green Bay. An eyewitness, Peter Pernin, described the ferocity of the fire in which many people died from suffocation rather than burning after the fire consumed all the available oxygen, and "large wooden houses [were] torn from their foundations and caught up like straws by two opposing currents of air which raised them till they came in contact with the stream of fire" (Pernin, 1971).

Three years later, a dry winter brought so little snow that spring log drives could not be floated down the St. Croix; small boys waded the river, bank to bank. By midsummer the stumpage was aflame again, generating heat "so terrific" that it burned "out all traces of stumps." In 1879, fires burnt out the homesteaders around Grantsburg, Wisconsin; "only when buildings in town were threatened did 'all the men and boys' turn out to fight it" (McMahon & Karamanski, 2002, Chapter 4, p. 12 [www.nps.gov/archive/sacn/hrs/hrs2k.htm]).

Another million acres burnt in stumpage in Lower Michigan leaving 169 bodies. Some of the survivors of that summer and of the Peshtigo Fire were still in the lumbering business in 1894, when the center of a ferocious lumbering season had shifted westward, across the St. Croix River, to the Minnesota town of Hinckley. Early in September, another Civil War veteran, General Christopher Columbus Andrews, now Fire Warden of Minnesota, presented a paper entitled ''Prevention of Forest Fires'' to the American Forestry Association, asserting the claim that fires were costing annually $25,000,000 and many lives. He concluded – ''For the American people thus to allow such calamities to habitually occur, without adopting any adequate means for their prevention causes our country to be regarded as in some respects only semi-civilized.''[9]

The railroad siding at the Minnesota lumbering town of Hinckley was stacked with lumber higher than any of the buildings on Main Street as Andrews was making his address, some said as high as the roof of the Congregational Church.

> The harvesting of pine … proceeded from the railroad toward the river … . By 1894, the town … was surrounded by vast stretches of combustible cutover land. As the summer fires spread unchecked from one field of slashings to the next they merged to form one great-unrestrained storm of flame, surging to the east then the west, directed only by the whims of the wind … . A little after noon when word came over the telegram that the town of Pokegama, just nine miles to the south, had been engulfed in flames. As word spread that most of Pokegama's inhabitants had been burned people at last awoke to their own danger. But it was too late … . The volunteer fire department barely had time to deploy to the edge of town when the monster fire struck. A wave of scorching, overwhelming, heat swept over the fire fighters as building after building broke out in flames … . Hinckley [was] transformed into an island in a sea of flames. (McMahon & Karamanski, 2002, Chapter 4, p. 11 [www.nps.gov/archive/sacn/hrs/hrs2k.htm])

> Several hundred people made it to a train sidetracked bedside the lumber mill. The heat was so great that the paint on the passenger cars was beginning to blister. The train sped through the blazing forest till it reached the town of Sandstone where it warned the inhabitants of the coming conflagration. The firestorm, however, was hard on their heels and within minutes of the train leaving Sandstone, that town was destroyed with the loss of forty-five people. When the train reached the trestle bridge over the Kettle River, they found it in flames. The engineer opened the throttle and the train made it across just before the bridge collapsed … . (McMahon & Karamanski, 2002, Chapter 4, p. 11 [www.nps.gov/archive/sacn/hrs/hrs2k.htm])

According to a contemporary account:

> Dogs, cats, chickens and stock were stricken instantly and died in their tracks without serious burns. In one instance a man was stricken down, but not burned enough to destroy his clothes, and in one of his pockets was found a small leather purse in which were four silver dollars welded together in one solid piece … . More than ninety discreet piles of gray ash, in human form, were later found along a railroad embankment … . Another group of about two hundred people ran for their lives up the track of the

> Mississippi and Lake Superior Railroad. As the flames gained on them the slow of foot perished one by one. Most of them, however, managed to keep running until they met a train. The train was unable to outrun the flames and it caught fire, but not before unloading its terrified passengers near a bog, into which they sought refuge. (Quoted in McMahon & Karamanski, 2002, Chapter 4, page 11 [www.nps.gov/archive/sacn/hrs/hrs2k.htm].)

The fire wiped out Hinckley and other Minnesota towns – Sandstone, Pokegama, Mission Creek, and Partridge – and killed 413 people. In Wisconsin, across the river, the hamlet of Phillips had gone to the flames in July. Barronett burned on the same day as Hinckley; "the refugees of Barronett no sooner found shelter in Shell Lake than flames surrounded that town. Although more than fifty buildings burned, Shell Lake was able to save its mill and the lives of its citizens. Among the other mill towns devastated that fire season were Comstock, Benoit, Marengo, and Mason. An estimated 1.4 million acres of pinelands and cutover was consumed by the fire." (McMahon & Karamanski, 2002, Chapter 4, p. 11 [www.nps.gov/archive/sacn/hrs/hrs2k.htm].)

Christopher Columbus Andrews kept up the good fight until he was in his early 90s, arguing that the best means of preventing catastrophe when fires struck was to keep the people out of the way of the fires. He pressed Minnesota to become better than "semi-civilized" by retiring large areas of the cutover from settlement, creating the state and national forests that in 2004 covered 17 million acres, one-third of the state. In 1902 the Chippewa National Forest, nearly 200,000 acres, became the first federal forest reserve approved by Congress, at his urging. One of the major reasons for its creation was a desire to reduce exposure of settlers to the consequences of "thinning" by contractors for big lumber companies who – then as now – operated at such low margins of profit that they were unwilling to pile branches and brush left behind after logging and conduct a controlled burn (Rice, 2002).

FIRE, PAIN AND POLICY

In New England, the experience was similar:

- In October 1825, lumbermen pressing into the north woods of Maine left stacks of slash and piles of sawdust that might be ignited by a lightning strike. The inevitable occurred – the ensuing fire burnt three million acres, showing no respect for the indistinct international boundary with New Brunswick.

- In October 1871, 3,780,000 acres burnt after lumbering in Wisconsin and upper Michigan. Fifteen hundred people were killed, five times as many as in the Great Chicago Fire of that year.
- In September 1881, a million acres of Lower Michigan burnt after lumbering. One hundred sixty nine bodies were counted.
- In September 1894, 418 people were killed in a fire in the lumbering town of Hinckley, Minnesota, which swept nearly 200,000 cutover acres. A million acres more burnt that summer in the lumbering areas of Wisconsin and Michigan.
- West Coast lumbering got underway seriously in the 1890, and in September 1902, thirty-eight people were killed in a million-acre blaze in Yacoult, Washington.
- Meanwhile, lumbering in the East went forward, and in April 1903 six hundred thousand acres burnt in the Adirondacks, in New York. Sporadic major fires continued in Maine – as recently as 1947 sixteen people died in a two hundred thousand acre fire.
- In October 1918, the lumbering towns of Cloquet and Moose Lake, Minnesota, went up in flames amid 250,000 acres – no one knows, exactly. Other sources say more than a million acres. We can be certain, however, that more than 450 people died, with many more imperiled as the fire leapt across the St. Louis River to come within two miles of the city of Duluth. The fire began in 400 carloads of dry lumber along the railroad. As if in vengeance, it turned its first fury upon the lumber mills themselves. When they had gone, it went on to burn out the homes of the people who worked there.

By the year 2000, the cutover lands of Wisconsin and Minnesota had begun to recover toward sustainable lumbering, after deliberate policy reduced the pace at which people were encouraged to settle in dangerous places. These Great Lakes states have not been as large receivers of in-migration as have those of the high, dry West, so their problem of managing human intrusions into danger have not been so severe as those of Arizona, New Mexico, and Colorado, yet the Midwest's population is distributing itself in accordance with channeling that has taken account of natural hazards. Few western states have followed the Midwestern lead – so far. The climate of Eastern states that are receiving heavy in-migration – Georgia, North Carolina, and Florida – is getting hotter, dryer, and experiencing wider extremes of weather. Global climate change is adding fire danger to their already perilous propensity to attract hurricanes and tornados. One need only drive through the currently dampened tinder-box counties from

Chapel Hill to Charlottesville, or look at the landscape beyond the strip-malls and traffic jams of the uphill suburbs of Atlanta, or hike the dense second and third growth now cluttering the once agricultural landscape between Boston and Worcester, imagining them a few degrees hotter and dryer, to understand that it will not long be possible for politicians to contend that fire is just a Western problem. North Carolina has famous foresters and schools of forestry. It also bears the scars of 20th century droughts that brought fire down from the lightning-punctuated mountains to the pine woods of the eastern lowlands.

Vermonters had learned early in the 19th century the lesson relearned in the Midwest by its middle decades, and reiterated by the National Forest Service in its report on the wildfires of the year 2000 – "it is after logging that damage from fire is greatest." This has been especially true when "Healthy Forest" plans or the simple economics of the lumber business drive mill owners to have "their timber … cut by contractors squeezed into operating at a low margin of profit" (Babbitt & Glickman, 2000). This was how it had been in the 1880s and 1890s, according to the National Park Service in its St. Croix River Report:

> [Whatever the big downriver operators might have preferred] these small businessmen were not inclined to take on the extra cost of piling the branches and brush left behind after logging and conducting a controlled burn. Although a generation of experience taught them better, they left behind the fuel for future forest fires. Farmers who purchased logged over land were confronted with acres of slash that could be removed economically only one way – by fire. A farmer working alone on his homestead lacked the ability to contain a blaze once it began. He merely doused his cabin with water and waited for the fire to stop of its own accord. Hundreds of fires set in this manner swept over the upper valley each year between 1890 and 1910. (McMahon & Karamanski, 2002, Chapter 4, p. 11 [www.nps.gov/archive/sacn/hrs/hrs2k.htm])

The Congress was, however, still listening to the lobbyists, and passed the Timber Cutting Act authorizing lumbering of the public domain either by homesteaders or mining companies. Wildcatting lumbermen could cruise the public lands, pick the likeliest stands, cut them down, and pay a fee – after the fact – of $1.25 per acre. Then the poorest of poor farmers would come in and try to homestead. Schurz urged his Liberal Republican friends to reform these policies. After the 10th try, the Forest Reserve "Creative" Act was passed in 1891 at his urging, empowering the President to hew "forest reserves" out of the public domain rather than open those reserves to homesteading. President Benjamin Harrison tugged Schurz back toward the Republican Party by creating the nation's first forest reservation. It included more than a million acres to the south of Yellowstone National Park in what is now primarily the Shoshone National Forest, and later added another 13 million acres in forest reserves.[10]

The 1891 "Creative Act" was indeed creative; it was as firm a statement as those of the Homestead and Morrill Acts that the Federal government could use its power as a landowner to favor one mode of settlement rather than another, and might even deny settlement in some areas when it was in the public interest to do so:

> [T]he President of the United States may, from time to time, set apart and reserve, in any State or Territory having public land bearing forests, in any part of the public lands wholly or in part covered with timber or undergrowth, whether of commercial value or not, as public reservations; and the President shall, by public proclamation, declare the establishment of such reservations and the limits thereof.

The nation was not yet willing to give life to this provision by providing money for a Schurz-style Civil Service to manage the parks or forests, the principal was firmly in place. Three years later the Department of Agriculture prohibited the "driving, feeding, grazing, pasturing or herding of cattle, sheep and livestock" on the forest reserves. Common sense had coalesced around the idea that some places were good for some things, some for others (Coville, 1977, p. 10; Dombeck et al., 2000).

That was two years after Speaker Joe Cannon had told John Weeks of Massachusetts that he could pass a bill to take the watersheds of the Connecticut and Merrimac Rivers out of settlement, including all that wildness now within the Green and White Mountain National Forests, if he could prove that doing so would diminish the flow of silt fouling the looms of the downstream woolen mills, but "not one cent for scenery." Those who tell this story are wont to leave out the essential fact that the Weeks Act passed – Weeks was like Stephen Mather, founder of the National Park Service, a businessman and master of economic data. When Weeks swung into action, the Old Man of the Mountain at Franconia Notch smiled.

Where the climate is hotter and drier, smoke and dust are nature's reminders of the presence of natural limits to settlement. They are similar physically and chemically. Fire tends to appear when there is more vegetation than dust on the surface of the earth. Drought brings them both forth to choke people and animals, and to make the earth for a time uninhabitable. It is cruel to encourage people to settle where they will be afflicted by either. Between 1931 and 1934 the Black Wind came upon the high dry plains, bearing both dust and smoke, and the sky over Chicago was yellow all summer. The political system responded during the New Deal years, and restoration commenced. The Civilian Conservation Corps (CCC) supplied an army of young men to redeem some of the errors of what might well be called "dust policy," as another will, I feel sure, emerge in the detritus of "fire policy." It is often forgotten how much of the present National Park System is there because the New Dealers believed in restoration of exhausted farm land. The National Industrial Recovery Act put the CCC into the restoration business by authorizing federal purchase of lands that had become "submarginal for farming but suitable for recreation."

After the Emergency Relief Administration took care of the afflicted people who had been trying to live upon the afflicted land, the Resettlement Administration helped them find new homes. Good precedents. The CCC men learned a lot, and so did the nation, lessons that ought now to inform its behavior in the face of land demonstrating itself to be "submarginal" for development in the face not only of dust but also of flood and fire as well. Upon the ravaged land, the CCC and the National Park Service went to work on 46 projects encompassing nearly 400,000 acres in 24 states. The Park Service became a restoration agency, supervising the work and adding more people to its rolls than it had again until a full generation later. The National Park System retained some of the restored areas. Few visitors to Acadia, Shenandoah, White Sands, Hopewell, Theodore Roosevelt, Manassas, Prince William, or Camp David, for that matter, are aware that they are enjoying restored land that was, in my youth, declared submarginal. Fire and dust had made them equivalents to mine dumps. They look better today. Three hundred thousand acres, now managed by the National Park Service and by state park systems, were withdrawn from agriculture in the 1930s as having been rendered unproductive and dangerous by past practices. The Federal flood insurance program, as revised recently by the Blumenauer–Bereuter Act, follows a similar course of action as to flood plains.[11]

The Congress of the New Deal years harkened back to a report issued in 1896 by the National Academy of Sciences, setting forth the principal of limits:

> Steep-sloped lands should not be cleared, the grazing of sheep should be regulated, miners should not be allowed to burn land over willfully, lands better suited for agriculture or mining should be eliminated from the reserves, mature timber should be cut and sold, and settlers and miners should be allowed to cut only such timber as they need. (Quoted in Dombeck, Wood, & Williams (2002; electronic) and Coville, (1977, p. 10))

That was a good doctrine for 2006, as it was in 1896. More, of course, is required. Candor should replace the current lack thereof on these matters. Risk-graduated data should be consistent and made available recorded in a National Risk Atlas, updated periodically as climates evolve, coastlines shrink, deserts expand, and water, fire, and dust spread. Further candor should encompass information to be provided to localities, states, and the Congress. At the household level, fire-wise principles can be ordained by neighbor-protects-neighbor basis. Communities can enforce such ordinances, as they increasingly do in Colorado (see Chapter 4 by Paterson for a further discussion of local fire safe planning). At the state level, highway policy, and state forest and park policy, can be better informed to provide green fire breaks with diminished fire load. And at the national level a wholesale re-evaluation of mortgage insurance, transportation, and tax-deduction policy is long overdue, taking account of natural hazards and the costs to the taxpayers of inducing migration into flame zones and paying to rescue people from them. Finally, a real fire policy, lowering fire loads close to existing communities, employing professional corps of people who know what they are doing on a regular basis, could learn much from the New Deal experience. Eventually, we will come to that; the only question is: how many people must die to make us willing to engage with the problem of a land rush into fire danger.

NOTES

1. It appears to be impossible to obtain from the Veterans Administration a breakdown of precisely how much mortgage insurance went into urban centers and how much of it outside. Since I obtained a GI Mortgage at the time, and for 10 years was a mortgage bankers' banker in the Midwest, I can rely only upon my own experience that it was virtually impossible to obtain such a mortgage in "crumbling urban neighborhoods" and easy in the suburbs. In Kennedy (2006) I offer the extensive evidence that this outcome was intentional – see especially Chapters 11 through 15, and 18 (pp. 151–223 and 248–260).

2. I shall not endnote or footnote data that are readily available in standard histories of the government agencies under discussion. In every instance, however, more extensive annotation to such sources, and to official websites in which they are presented, are available in Kennedy (2006). The detailed data and citations for Cold War dispersion strategies appear in Chapters 1, 3, 4, and 5 of that work. References for the wildfire-industrial complex are in Chapters 17 and 18.

3. The history of recognition of the need to channel internal migration away from fire-prone areas appears in Kennedy (2006), Chapters 11 through 15, and 18 (pp. 151–222 and 248–260).

4. County-by-county data are available from the U.S. Bureau of the Census. County-by-county maps, generated by my team of researchers, and by others at the Universities of Wisconsin and Colorado, appear in Kennedy (2006).

5. I have compiled the trillion dollar total from data provided by FNMA, GNMA, and their predecessors. Their websites use aggregates, and their individual publications show annual rates.

The annual cost of post-fire recovery is only subject to estimates. I have used the best available data from the National Park Service and the U.S. Forest Service, as confirmed through efforts on the part of the office of Congressman Earl Blumenauer. They are not, however, sufficiently comprehensive nor precise to satisfy rigorous scholarly standards.

6. The best source for general discussion of these matters would be any of the works of Stephen Pyne; that most apposite to the matters under discussion here is Pyne (2004).

7. Detailed history of the Cold War dispersion strategy and detailed citations, are offered in Chapters 1 through 5 of Kennedy (2006), pp. 3–78.

8. The environmental consequences of plantation agriculture vs. ''yeoman'' farming are set forth in Kennedy (2003), Chapters 1 through 6. The land distribution preferences of Jefferson and Hamilton are stated and annotated in these chapters and also in Kennedy (2000).

9. Andrews (1894), pp. 179–182 as quoted in Rice (2002). Rice's is the best biographical and analytical work on General Christopher Columbus Andrews done so far – astonishingly competent and capacious. That she was a high school student makes it even more remarkable. I have followed her lead to many of her sources at the Minnesota Historical Society, and in each instance she was accurate and her bibliographical notes perspicacious. Her exhaustive bibliography on this important historical figure is available along with the article text at http://www.historycooperative.org/journals/ht/36.1/rice.html.

10. Schurz is the primary subject of Chapter 10 of Kennedy (2006).

11. The CCC and National Park Service experience is well described in the official history of the latter, as available on its website. See also National Park Service (2005), pp. 56–57.

REFERENCES

Andrews, C. C. (1894). The prevention of forest fires. *Proceedings of the American Forestry Congress*. Washington, DC: Judd and Detweiler, Printers (pp. 179–182).

Babbitt, B., & Glickman, D. (2000). *Managing the Impact of Wildfires on Communities and the Environment: A Report to the President In Response to the Wildfires of 2000*. U.S. Department of Agriculture and U.S. Department of Interior.

Coville, F. (1977). *Forest Growth and Sheep Grazing in the Cascade Mountains of Oregon*. U.S. Department of Agriculture, Division of Forestry Bulletin no. 15.

Dombeck, M., Wood, C., & Williams, J. (2000). *From conquest to conservation: Our public lands legacy* (p. 20). New York: Island Press. (Electronic version available on the web.)

Dombeck, M., Wood, C., & Williams, J. (2002). *From conquest to conservation: Our public lands legacy*. New York: Island Press.

Gough, R. (1991). Richard T. Ely and the development of the Wisconsin cutover. *Wisconsin Magazine of History*, *75*(Autumn), 3–38.

Kennedy, R. G. (2000). *Burr, Hamilton and Jefferson: A study in character*. New York: Oxford University Press.

Kennedy, R. G. (2003). *Mr. Jefferson's lost cause: Land farmers, slavery and the Louisiana Purchase*. New York: Oxford University Press.

Kennedy, R. G. (2006). *Wildfire and Americans, how to save lives, property, and your tax dollars*. New York: Hill and Wang.

McMahon, E. M., & Karamanski, T. J. (2002). *Time and the rivers: A history of the St. Croix*. Omaha, NE: National Park Service.

Monson, D., & Monson, A. (1951). A program for dispersal. *Bulletin of the Atomic Scientists*, *7*, 244–250.

National Park Service. (2005). *The national parks: Shaping the system*. Washington, DC: U.S. Dept of Interior.

Nesbit, R. (1973). *Wisconsin: A history*. Madison: The University of Wisconsin Press.

Pernin, P. (1971). *The Great Peshtigo fire: An eyewitness account*. Madison, WI: Sate Historical Society of Wisconsin. Available at http://www.peshtigofire.info/gallery/peshtigo_philyaw.htm.

Pyne, S. (2004). *Tending fire: Coping with America's wildland fires*. Washington, DC: Island Press.

Rice, A. (2002). General Christopher C. Andrews: Leading the Minnesota forestry revolution. *The History Teacher*, *36*(1), 91–115. Available at http://www.historycooperative.org/journals/ht/36.1/rice.html.

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CHAPTER 3

FIRE POLICY IN THE URBAN–WILDLAND INTERFACE IN THE UNITED STATES: WHAT ARE THE ISSUES AND POSSIBLE SOLUTIONS?

Scott L. Stephens and Brandon M. Collins

ABSTRACT

The urban–wildland interface (UWI) poses a series of challenges to both rural and urban communities in the United States. Some efforts have been developed to promote the use of fire-resistant building materials and creation of defensible space; few comprehensive laws address the threat of external ignitions on structures. Most problems associated with the private side of the UWI are centered on land planning methods. Communities and counties must be encouraged to take more active roles in wildfire protection and this will require a fundamentally new method of land planning and review authority. Without substantial changes in land planning, we will continue to experience large losses of structures and life in the UWI.

INTRODUCTION

The urban–wildland interface (UWI) is an area where structures are built among and next to forests, shrublands, and grasslands. The UWI poses a

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series of challenges to both rural and urban communities including ecosystem fragmentation, increased exposure to invasive species, water and air pollution, wildfire, and loss of wildlife habitat (Alavalapaite, Carter, & Newman, 2005). These challenges are exacerbated by the vulnerability of the UWI to rapid land-use change throughout the United States. Addressing these concerns in the complex and changing landscapes at the UWI requires the implementation of clear and effective policies.

Across the conterminous U.S., the UWI covers 719,156 km^2 (9.4% of the total land area) and reportedly contains 44,348,628 housing units (38.5% of all housing units) (Radeloff et al., 2005). Major UWI areas are located along the west coast of the U.S., the Colorado Front Range, southeast Texas, and the northern Great Lakes States. The UWI is also common on the fringe of major metropolitan centers such as Los Angeles, Seattle, Denver, Dallas, Atlanta, Washington DC, New York, and Boston (Radeloff et al., 2005). The area being converted to UWI continues to increase in the U.S.

The environmental consequences of the UWI are becoming increasingly evident. U.S. Forest Service Chief Dale Bosworth (2003) has identified the UWI and further land conversion to this use as one of the four main threats to public and private forests in the U.S. Public concern about the social and environmental impacts of the UWI has grown in recent years (Bengston, Potts, Fan, & Goetz, 2005).

Throughout the western U.S. many key public concerns center on fire in the UWI. Fire poses a direct and obvious threat to lives and structures. As such, fires are eliminated from UWI systems to the fullest extent possible. The consequences of escaped fires in the UWI far exceed those in wildland areas. As a result, policy makers and land managers have focused much attention on alleviating the threat of fire in the UWI.

Programs have been initiated throughout the U.S. to address fire problems in the UWI. These include zoning, growth boundaries, land acquisition, education, community assistance programs, and provision of conservation easements (many of which are discussed by Robert Paterson in Chapter 4). Additionally, there has been growth in referenda and ballot measures where citizens have placed restrictions on future development in the UWI (Bengston et al., 2005). Debates currently exist over the specific types of fire hazard reduction treatments appropriate in relatively remote U.S. federal forests (Stephens & Ruth, 2005; Stephens, 2005). However, the consensus regarding fire hazard reduction in the UWI is that treatments should reduce surface, ladder, and canopy fuels, regardless of forest types (e.g., ponderosa pine, mixed conifer, lodgepole pine) (Agee & Skinner, 2005).

Several recent federal fire policies such as the National Fire Plan (USDA-USDI 2000), the Collaborative Approach for Reducing Wildfire Risks to Communities and the Environment: Ten-Year Comprehensive Strategy (TYCS) (WGA, 2001), and the Healthy Forest Restoration Act (HFRA, 2003) have specifically addressed fire management in the UWI. The National Fire Plan and TYCS recognizes that key decisions in setting priorities for restoration and fuels management should be made collaboratively at local levels (Stephens & Ruth, 2005). The HFRA specified that 50% of fuels treatments should be done to reduce hazards in the UWI. This has led to the creation of community-based efforts (discussed further in Chapter 9 by David Ganz et al. and Chapter 10 by Patricia Stokowski) that are reducing fire hazards in the UWI using collaborative agreements (Reams, Haines, Renner, Wascom, & Kungre, 2005).

Some efforts have been developed in the U.S. to promote the use of fire-resistant building materials and creation of defensible space in the UWI. The use of combustion-resistant building materials has been shown to be of paramount importance regarding structural survival during wildfires in the U.S. (Cohen, 2000) and Australia (Leonard, Leicester, & Bowditch, 2003). While these aspects are critically important in determining structural survival, few comprehensive laws or statutes exist in the U.S. addressing the threat of external ignitions on structures. One of the reasons for this lack of regulation governing the private side of the UWI is the American spirit of individualism which resents government interference in closely guarded personal rights (McCaffrey, 2004; Mileti, 1999).

The objective of this chapter is to present specific ideas to reform and improve U.S. fire policy and management in the UWI. To be achieved, substantive reform requires better development, dissemination, and utilization of scientifically based information (Franklin & Agee, 2003). The ensuing discussion will develop a conceptual agenda for this policy. Information from this paper should be of interest to planners, managers, and policymakers working in or near the UWI.

NEW POLICY INITIATIVES

Fire cannot be eliminated entirely from the UWI. Staffing of fire management agencies to a level at which all fires are detected and suppressed at a small size is not possible. Under extreme conditions, fire suppression activities may have little or no effect on fire spread (Graham, 2003; Moritz, Keeley, Johnson, & Schaffner, 2004). The 2003 wildfires in southern

California serve as a recent example of the threat that uncontrollable wildfires pose on communities in the UWI. More than 299,000 ha burned in the 2003 southern California wildfires and approximately 3,600 structures were lost (NIFC, 2004; Reams et al., 2005; Stephens & Sugihara, 2006), which was one of the largest structural losses from any wildfire in North America. Efforts to alleviate the threat of wildfire in the UWI have primarily focused on wildland fuel reduction, and have not been consistent between the public and private sectors.

The National Fire Plan and TYCS highlighted and provided funds to reduce fire hazards primarily on the federal wildland side of the UWI. Common fuel treatments used on federal lands that abut the UWI are defensible fuel profile zones (DFPZs) (another name for this treatment is shaded fuel breaks) (Agee et al., 2000; Kalabokidis & Omi, 1998; Stephens & Ruth, 2005; Husari et al., 2006). DFPZs are linear landscape elements approximately 0.5–1.0 km wide, typically constructed along roads to break up fuel continuity and provide a defensible zone for fire-suppression forces.

When located near communities, DFPZs can be effective in providing a safe area for fire suppression forces to stop a wildland fire from entering or leaving the private structural side of the UWI. The reduced ladder, surface, and crown fuels in these linear elements will not stop a wildfire, but the behavior of such fires will be reduced inside the DFPZ. Fire behavior can change from a high severity crown fire outside of the DFPZ to a surface fire within it. However, the effectiveness of DFPZs is highly dependent on fire weather. These treatments are generally designed to reduce fire behavior to a controllable level under moderate or possibly high-fire weather conditions, and will not be effective during extreme fire weather because of spot fire initiation.

In some conditions fire suppression forces can initiate a backfire anchored on the DFPZ. Backfires are ignited with the objective of consuming unburned fuel between a suppression point and an approaching wildfire front, and can serve as a very successful suppression strategy. However, as with a wildfire, backfires are influenced by wind, fuels, and topography, and as such, there is risk in implementing such operations. This was evident in the 2000 Los Alamos wildfire, where a backfire contributed to structural losses in Los Alamos, New Mexico.

With the financial resources and emphasis on treating lands in the UWI provided in the National Fire Plan and Health Forests Restoration Act, many areas of federal lands that are adjacent to homes are being treated to reduce hazards. However, as the UWI continues to expand in the many areas throughout the U.S., costs of providing pre-fire protection (fuel reduction activities) and protection from encroaching wildfires are exacerbating already increased wildfire-related expenditures. As budgets at the federal and state level are unable to keep up with these increasing costs, more responsibility is being placed on local governments and fire services to provide wildfire protection. Local engagement is critical to this process and has been provided by Fire Safe Councils (described further in Chapter 9 by David Ganz et al.), which channel National Fire Plan funds to local communities for pre-fire projects. Many western and southern states have also partnered with the federal agencies to reduce fire hazards in the UWI. Partnerships are particularly important because fire does not respond to artificial boundaries.

One critical aspect of fuels treatments along the UWI is maintenance. Maintenance is important because trees and shrubs will continue to grow and eventually will produce another high-hazard fuel bed. It is therefore absolutely critical that plans and financial resources are available to maintain the DFPZs and other fuel treatments along the UWI. Many federal and state plans are creating DFPZs in appropriate areas but long-term funding and staffing to maintain their effectiveness has not been provided. It is not enough to continue to install these structures, plans and funding must be available for their maintenance.

While the federal wildland side of the UWI has begun to take steps to reduce fire hazards, the private side has not kept up. Fuel treatments along the UWI will be effective in reducing structural losses only if they are used in combination with combustion-resistant homes that have defensible space from wildland and domestic vegetation (Cohen, 2000; Leonard et al., 2003; Moritz & Stephens, 2006; Stephens & Ruth, 2005). Without substantial improvements on the private structural side of the UWI, we will continue to experience large losses from wildfires in the U.S. As said above, fuels treatments along the UWI will not eliminate fires, they will only modify their behavior. If homes with combustible roofs, exposed wooden decks, and low defensible space continue to dominate the UWI, they will still be lost during wildfires. Fires do not discriminate; the most combustible elements will burn, and if the most combustible features are homes, they will be lost.

Many problems associated with the private side of the UWI in the U.S. are centered on land planning methods (see Chapter 4 for further discussion of land use planning and smart growth policies related to wildfire management). In the western U.S., individual counties make land planning decisions primarily based on local needs. Counties promote growth to increase local tax revenues, which leads to more fragmented landscapes and increases in the area dominated by the UWI. Long-term consequences are seldom included in county plans and coordination with adjacent counties or other land-management agencies are relatively rare. The result is an ever-expanding UWI that places more and more assets and people at risk (Stephens & Sugihara, 2006). The western U.S. will never solve the private side of the UWI with such a system in place. Large amounts of financial resources invested in federal or state wildlands in the UWI will only produce modest benefits in terms of the number of structures lost during wildfires.

Even if large federal or state funds could be allocated to UWI communities, issues of equity arise when considering the disproportionate use of taxpayers' dollars to subsidize wildfire protection in the UWI. This inequity is compounded by the unbalanced allocation of fire suppression resources towards the UWI. During fires that pose any threat to communities, fire suppression resources are primarily focused on protecting lives and structures the UWI. This substantially reduces the capacity of fire-protection agencies to suppress unwanted fire in more remote wildlands. The ecological impacts of this prioritization towards the UWI should be considerable when managing the more remote wildlands. The lack of suppression resources could result in more accelerated losses of sensitive wildlife habitat or plant communities (e.g., old growth, threatened and endangered species). Another form of land management planning is critically needed in this area.

THE AUSTRALIAN EXPERIENCE

The people of Australia have also experienced large losses from fires in the UWI. For the first 150 years of white settlement in Australia, the destruction of houses during wildfires (bushfires) was taken as inevitable, and few efforts were made to investigate or improve the performance of buildings in wildfire-prone areas (Leonard et al., 2003). Beginning in about 1940, Australian researchers gathered information from a series of wildfires that enabled them to promote new policies and construction methods to reduce wildfire losses.

Before this analysis began, there were widespread community beliefs in Australia that wildfire moved at the speed of express trains, that houses exploded into flames and burnt down in minutes, and that there was not much that could be done to prevent this (Leonard et al., 2003). Research has shown that the majority of houses destroyed in Australian wildfires actually survive the passage of the fire front only to burn down in the following hours due to fire spread from ignitions caused by windborne burning debris

(Leonard et al., 2003). This prolonged ember attack mechanism (spotting) is the main cause of structural losses in the UWI.

Since the inception of rural fire brigades in the 1940s and the formalization of wildfire research in Australia, much has been achieved in mitigating risk to life and property (Leonard & McArthur, 1999). The main lessons learned in Australia are

(1) Fire brands are the dominant spread mechanism during high severity wildfires.
(2) Homes must be designed and built to resist ember attack.
(3) If a homeowner is well prepared, staying with the home during a wildfire and actively defending it following the passage of the fire front will greatly increase the probability of the home surviving the fire.

Similar building performance criteria could be applied in the U.S., but this would require a fundamental shift in the way that we do land planning. Counties and local governments would have to relinquish some of their authority or be subject to a review based on how a proposed action would change wildfire risk. Passing some of the authority to make decisions to a higher level (possibly the State) could allow for efficient and critical review in reference to wildfire. In New South Wales, Australia, new subdivisions must pass a fire review at the state level and all in-building must also pass a regulatory review. This has led to development that is much more strategic concerning wildfires. The counties in the western U.S. could also move to such a program but this would require a fundamental shift in land planning that maybe difficult to achieve because of our high value in individual freedoms and private property rights.

The Australian idea that able bodied and prepared homeowners can reduce losses in the UWI by staying in the home and actively defending it following the passage of the fire front is quite contrary to the evacuation strategy employed by the U.S. However, if homes and adjacent vegetation have previously been prepared to resist ember attack, the ability of a home to survive wildfire will be greatly enhanced by small-scale suppression efforts. The strategy entails a homeowner having basic suppression tactics and equipment that can be used to extinguish spot fires. As stated above, most structures in the UWI are ignited by burning debris (i.e., fire brands or spots), not by direct flaming combustion or radiation heat transfer. Fire brands initially ignite very small fires that can be extinguished by private citizens. Of course structures and adjacent vegetation must first be well prepared to resist fire, something that is rare in the U.S. Most homes in the UWI in the western U.S. are highly combustible and have low defensible space. Such conditions are not conducive to a homeowner supported fire suppression policy and it would be dangerous to adopt such a policy without fundamental reform in the way we build structures.

CONCLUSION

It is logical that the first step to improve UWI policy is to reform U.S. building and land planning methods to incorporate wildfire performance criteria. Although there are some small-scale, community-based projects that are making a difference in the UWI, much more must be done. Communities must be encouraged to take more active roles in wildfire protection. This would result in increased local accountability, and ultimately self-reliance. This will require a fundamentally new method of land planning and review authority. We cannot continue to expand the area dominated by the UWI and expect wildfire losses to decrease.

Other forces such as global climate change (Clark, 1988; Fried, Torn, & Mills, 2004; Karl, 1998; Moritz & Stephens, 2006; Swetnam & Betancourt, 1990; Torn & Fried, 1992) may further complicate fire management in the UWI. Climate change may lead to differences in plant distributions (Bachelet, Neilson, Lenihan, & Drapek, 2001), lightning frequency (Price & Rind, 1994), and could also increase the length of fire season. These changes would further exacerbate wildfire hazards and risks in the UWI.

The National Fire Plan, the Collaborative Approach for Reducing Wildfire Risks to Communities and the Environment: TYCS, and the Healthy Forest Restoration Act have all targeted fire hazard reduction in the UWI. This could produce a more sustainable landscape if the private side of the UWI also takes actions to reduce their hazards and risks. Increased investment in the federal side of the UWI can reduce the resources available to treat relatively remote forested areas. Many watersheds, wildlife habitats, and old-growth forests are currently at risk from uncharacteristic high-severity wildfires because of the effects of a century of fire suppression and past harvesting (see Chapter 2 by Roger Kennedy for a further discussion of this topic). Targeting our financial and political resources to the UWI may be desirable to the people that choose to live in these environments but will do little to solve our diverse fire management problems in remote areas.

The creation of new fire policies depends on technical and scientific information, but the choices made are inherently political ones (Stephens & Ruth, 2005). For this reason, even if a particular issue is relatively uncomplicated and the design of a solution may be easily understood, policy formulation is often complicated. Budgetary concerns, for example, may override even the soundest proposals. With this background it will be critical to develop political support at the local, regional, and state levels to begin to initiate the reforms outlined in this paper. Without substantial changes in land planning, we will continue to experience large losses of structures and life in the UWI.

REFERENCES

Agee, J. K., Bahro, B., Finney, M. A., Omi, P. N., Sapsis, D. B., Skinner, C. N., van Wagtendonk, J. W., & Weatherspoon, C. P. (2000). The use of shaded fuelbreaks in landscape fire management. *Forest Ecology and Management*, *127*, 55–66.

Agee, J. K., & Skinner, C. N. (2005). Basic principals of forest fuel reduction treatments. *Forest Ecology and Management*, *211*, 83–96.

Alavalapaite, J. R., Carter, D. C., & Newman, D. H. (2005). Wildland–urban interface: Challenges and opportunities. *Forest Policy and Economics*, *7*, 705–708.

Bachelet, D., Neilson, R. P., Lenihan, J. M., & Drapek, R. J. (2001). Climate change effects on vegetation distribution and carbon budget in the United States. *Ecosystems*, *4*, 164–185.

Bengston, D. N., Potts, R. S., Fan, D. P., & Goetz, E. G. (2005). An analysis of public discourse about urban sprawl in the United States: Monitoring concern about a major threat to forests. *Forest Policy and Economics*, *7*, 745–756.

Bosworth, D. (2003). *Is America on track toward sustainable forests*? Keynote Presentation, Society of American Foresters Annual Convention, October 26, 2003.

Clark, J. S. (1988). Effects of climate change on fire regimes in Northwestern Minnesota. *Nature*, *334*, 233–235.

Cohen, J. D. (2000). Preventing disaster: Home ignitability in the wildland–urban interface. *Journal of Forestry*, *98*, 15–21.

Franklin, J. F., & Agee, J. A. (2003). Forging a science-based national forest fire policy. *Issues in Science and Technology*, *20*, 59–66.

Fried, J. S., Torn, M. S., & Mills, E. (2004). The impact of climate change on wildfire severity: A regional forecast for Northern California. *Climatic Change*, *64*, 169–191.

Graham, R. T. (Ed.). (2003). *Hayman fire case study*. Gen. Tech. Report RMRS-GTR-114, p. 396. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

HFRA (2003). Healthy forest restoration act. H.R. 1904. United States Congress, Washington, DC. Retrieved December 8, 2005 from http://www.healthyforests.gov/.

Husari, S., Nichols, H. T., Sugihara, N. G., & Stephens, S. L. (2006). Fire and fuel management. In: N. G. Sugihara, J. W. van Wagtendonk, K. E. Shaffer, J. Fites-Kaufman & A. E. Thode (Eds), *Fire in California's ecosystems* (pp. 444–465). Berkeley, CA: University of California Press.

Kalabokidis, K. D., & Omi, P. N. (1998). Reduction of fire hazard through thinning residue disposal in the urban interface. *International Journal of Wildland Fire*, *8*, 29–35.

Karl, T. R. (1998). Regional trends and variations of temperature and precipitation. In: R. T. Watson, M. C. Zinyowera, R. H. Moss & D. J. Dokken (Eds), *The regional impacts of climate change: An assessment of vulnerability* (pp. 412–425). Cambridge, MA: Cambridge University Press.

Leonard, J. E., Leicester, R. H., & Bowditch, P. A. (2003). Bushfire catastrophe: Myth or fact? In: N. R. Britton (Ed.), *Proceedings of the Conference on Catastrophic Risks and Insurability* (pp. 1–9). *Australia's 8th Hazards and Capital risk Management Conference*, Gold Coast, Queensland, Australia, August 17–19.

Leonard, J. E., & McArthur, N. A. (1999). A history of research into building performance in Australian bushfires. *Proceedings Bushfire 99: Australian Bushfire Conference*, Albury, Australia, July 7–9, Australia School of Environmental and Information Sciences, Charles Stury University (pp. 219–225).

McCaffrey, S. (2004). Thinking of wildfire as a natural hazard. *Natural Resources Journal*, *17*, 509–516.

Mileti, D. S. (1999). *Disasters by Desing: A reassessment of natural hazards in the United States*. Washington, DC: Joseph Henry Press.

Moritz, M. A., Keeley, J. E., Johnson, E. A., & Schaffner, A. A. (2004). Testing a basic assumption of shrubland fire management: How important is fuel age? *Frontiers in Ecology and the Environment*, *2*, 67–72.

Moritz, M. A., & Stephens, S. L. (2006). *Fire and sustainability: Considerations for California's altered future climate*. White paper, California Climate Change Center, publication CEC-500-2005-192-SD. Sacramento, CA.

NIFC. (2004). National Interagency Fire Center. Urban–wildland and wildland fire statistics. Boise, ID. Retrieved from http://www.nifc.gov/.

Price, C., & Rind, D. (1994). The impact of a $2\times$ CO_2 climate on lightning caused fires. *Journal of Climate*, *7*, 1484–1494.

Radeloff, V. C., Hammer, R. B., Stewart, S. I., Fried, J. S., Holcomb, S. S., & McKeefry, J. F. (2005). The wildland–urban interface in the United States. *Ecological Applications*, *15*, 799–805.

Reams, M. A., Haines, T. K., Renner, C. R., Wascom, M. W., & Kungre, H. (2005). Goals, obstacles and effective strategies of wildfire mitigation programs in the wildland–urban interface. *Forest Policy and Economics*, *7*, 818–826.

Stephens, S. L. (2005). Forest fire causes and extent on United States Forest Service lands. *International Journal of Wildland Fire*, *14*, 213–222.

Stephens, S. L., & Ruth, L. W. (2005). Federal forest fire policy in the United States. *Ecological Applications*, *15*, 532–542.

Stephens, S. L., & Sugihara, N. G. (2006). Fire management and policy since European settlement. In: N. G. Sugihara, J. W. van Wagtendonk, K. E. Shaffer, J. Fites-Kaufman & A. E. Thode (Eds), *Fire in California's ecosystems* (pp. 431–443). Berkeley, CA: University of California's Press.

Swetnam, T. W., & Betancourt, J. I. (1990). Fire-southern oscillation relations in the Southwestern United States. *Science*, *249*, 1017–1020.

Torn, M. S., & Fried, J. S. (1992). Predicting the impact of global warming on wildfire. *Climatic Change*, *21*, 257–274.

WGA. (2001). A collaborative approach for reducing wildland fire risk to communities and the environment: 10-year comprehensive strategy. Western Governors' Association. Retrieved December 8, 2005 from www.westgov.org/wga/initiatives/fire/final_fire_rpt.pdf.

CHAPTER 4

WILDFIRE HAZARD MITIGATION AS "SAFE" SMART GROWTH

Robert G. Paterson

ABSTRACT

Over the last 30 years, despite immense and increasing expenditures by the federal government for disaster preparedness and relief, both catastrophic and chronic losses from natural hazards have continued to increase at an alarming pace. Although earthquakes, floods, tornadoes, and hurricanes account for the largest portion of these natural hazard losses, wildfire increasingly represents significant disaster losses of well over a billion dollars annually. There is considerable concern that losses from wildfires will only increase in the U.S. as some of the highest growth rates in the nation, both metropolitan and nonmetropolitan types of growth, are projected to continue in states with extensive wildland fire hazard areas. The land development patterns associated with that growth are problematic because so much of the development in the last 30 years (and that is still occurring) is not being steered away from the highest wildfire hazard settings, nor are adequate steps being taken to ensure that when development occurs in high wildfire hazard zones appropriate mitigation is used to reduce the vulnerability of people and property to loss. Fortunately, those anticipated future wildfire losses have a great potential to be reduced provided state and local governments take the initiative to create partnerships to ensure "safer" and "smarter" patterns of land development occur in and near wildland–urban interface areas. This

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chapter explores wildfire mitigation planning as an integral component of "safe smart growth" for wildland–urban interface communities.

WILDFIRE HAZARD MITIGATION AS "SAFE" SMART GROWTH

Over the last 30 years, despite immense and increasing expenditures by the federal government for disaster preparedness and relief (average annual disaster losses are estimated at $25–30 billion annually in the U.S.), both catastrophic and chronic losses from natural hazards have continued to increase at an alarming pace (Mileti, 1999). Although earthquakes, floods, tornadoes, and hurricanes account for the largest portion of these natural hazard losses, wildfire increasingly represents significant disaster losses of well over a billion dollars.[1] Indeed, NOAA's national climatic data system shows that from 1980 to 2004, wildfires were the most frequent weather-related billion dollar-plus disaster in the Western half of the U.S. (surpassing even floods) (NOAA, 2005). However, it would be a grave error to think that wildfire hazards and losses are strictly a western U.S. phenomenon (see Chapter 1 by Troy and Kennedy and Chapter 2 by Kennedy for further discussion of wildfires outside of the western U.S.). The summer of 1998, witnessed wildfires destroying nearly 500,000 acres and over 240 structures throughout Florida with an estimated cost of $890 million (Paterson, 2001). Indeed, as shown in Fig. 1 and Table 1 on the following pages, more than 2/3rds of the states nationwide could identify significant wildland–urban interface fire losses reflecting a broad range of wildland–urban interface conditions from 1980 to 2000 (Paterson, 2001).[2]

As we progress into the early part of the 21st Century, there is considerable concern that losses from wildfires will only increase in the U.S. For example, Platt (1998) writing on behalf of the National Academies' Urban Wildland Fire Forum notes that approximately 15% of the U.S. population or 38.6 million people currently live "at risk" in wildland–urban interface areas, and that some of the highest growth rates in the nation, both metropolitan and nonmetropolitan types of growth, are projected to continue in states with extensive wildland fire hazard areas (e.g., Nevada, Arizona, Colorado, Utah, and Idaho). The land development associated with that population growth is problematic because so much of the development in the last 30 years (and that is still occurring) is not being steered away from the highest wildfire hazard settings, nor are adequate steps being taken to ensure that when development occurs in high wildfire hazard zones

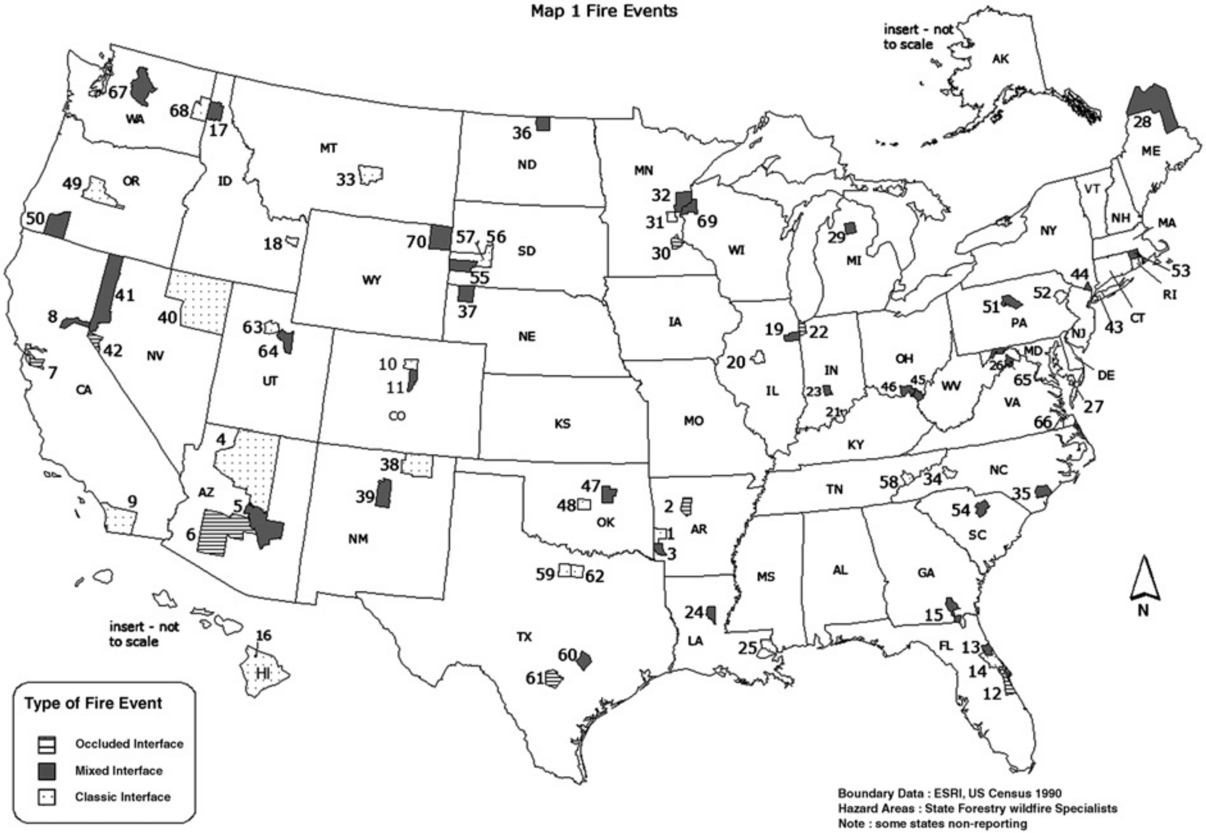

Fig. 1. Worst Wildland–Urban Interface Fire Events 1980–2000.

Table 1. Worst Wildland-Urban Interface Fire Events by State 1980–2000 (references Fig. 1).

Label	County Name, State	Type
1	Polk, AR	Classic
2	Pope, AR	Occluded
3	Sevier, AR	Mixed
4	Coconino, AZ	Classic
5	Gila, AZ	Mixed
6	Maricopa, AZ	Occluded
7	Alameda, CA	Occluded
8	Nevada, CA	Mixed
9	San Diego, CA	Classic
10	Boulder, CO	Classic
11	Jefferson, CO	Mixed
12	Brevard, FL	Occluded
13	Flagler, FL	Mixed
14	Volusia, FL	Classic
15	Ware, GA	Mixed
16	Hawaii, HI	Classic
17	Kootenai, ID	Mixed
18	Madison, ID	Classic
19	Kankakee, IL	Mixed
20	Tazewell, IL	Classic
21	Floyd, IN	Classic
22	Lake, IN	Occluded
23	Monroe, IN	Mixed
24	La Salle, LA	Mixed
25	St. Tammany, LA	Classic
26	Allegany, MD	Mixed
27	Somerset, MD	Classic
28	Aroostook, ME	Mixed
29	Crawford, MI	Mixed
30	Dakota, MN	Occluded
31	Isanti, MN	Classic
32	Pine, MN	Mixed
33	Musselshell, MT	Classic
34	Burke, NC	Classic
35	Pender, NC	Mixed
36	Rolette, ND	Mixed
37	Dawes, NE	Mixed
38	Colfax, NM	Classic
39	Santa Fe, NM	Mixed
40	Elko, NV	Classic
41	Washoe, NV	Mixed
42	Douglas, NV	Occluded
43	Nassau, NY	Classic

Table 1. (*Continued*)

Label	County Name, State	Type
44	Rockland, NY	Mixed
45	Lawrence, OH	Mixed
46	Scioto, OH	Mixed
47	Creek, OK	Mixed
48	Oklahoma, OK	Classic
49	Deschutes, OR	Classic
50	Jackson, OR	Mixed
51	Clinton, PA	Mixed
52	Monroe, PA	Classic
53	Providence, RI	Mixed
54	Kershaw, SC	Mixed
55	Custer, SD	Mixed
56	Pennington, SD	Classic
57	Pennington, SD	Occluded
58	Sevier, TN	Classic
59	Jack, TX	Classic
60	Bastrop, TX	Mixed
61	Bexar, TX	Occluded
62	Wise, TX	Classic
63	Salt Lake, UT	Classic
64	Wasatch, UT	Mixed
65	Frederick, VA	Mixed
66	Suffolk, VA	Classic
67	Chelan, WA	Mixed
68	Spokane, WA	Classic
69	Burnett, WI	Mixed
70	Crook, WY	Mixed

appropriate mitigation is used to reduce the vulnerability of people and property to loss (Davis, 1990; Mileti, 1999; Platt, 2001). Those expectations for rising urban–wildland interface fire losses are shared by a large majority of state foresters knowledgeable about their states' wildland–urban interface hazards.[3] Eighty-seven percent of the states reported that they expected wildland–urban interface hazards to somewhat or greatly increase over the next decade given projected demographic trends. Moreover, 85% of the states reported that only 30% or less of the communities "at-risk" of wildfire in their state have adequate wildfire hazard mitigation programs in place to reduce losses. Fig. 2 and Table 2 illustrate some of those most at risk places in the U.S. as identified by state foresters.

Fortunately, those anticipated future wildfire losses have great potential to be reduced provided state and local governments take the initiative to

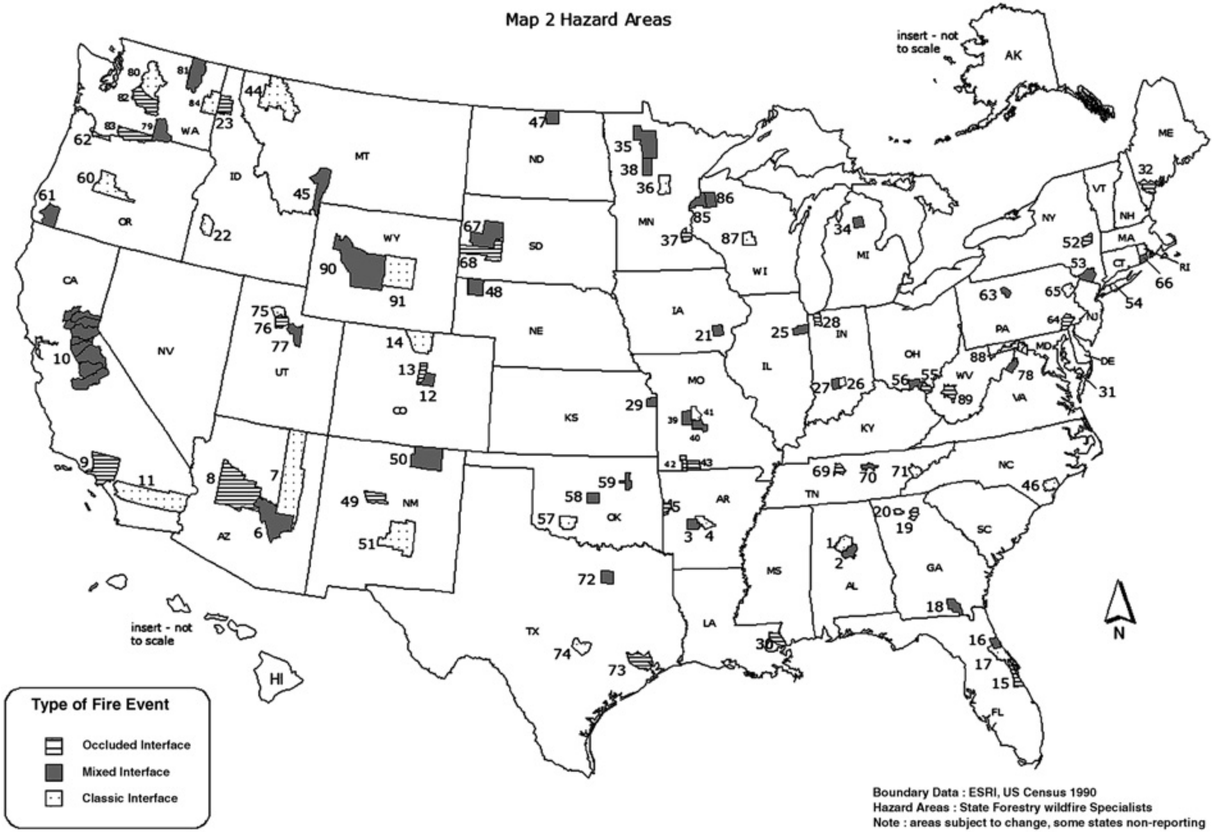

Fig. 2. Highest Wildland–Urban Interface Fire Hazards 1980–2000.

Table 2. Highest Wildland-Urban Interface Fire Hazard Areas for 2000 (references Fig. 2).

Label	County Name, State	Type
1	Jefferson, AL	Classic
2	Shelby, AL	Mixed
3	Garland, AR	Mixed
4	Saline, AR	Classic
5	Sebastian, AR	Occluded
6	Gila, AZ	Mixed
7	Navajo, AZ	Classic
8	Yavapai, AZ	Occluded
9	Los Angeles, CA	Occluded
10	Sierra Nevada Foothills, CA	Mixed
11	Riverside, CA	Classic
12	Douglas, CO	Mixed
13	Jefferson, CO	Occluded
14	Larimer, CO	Classic
15	Brevard, FL	Occluded
16	Flagler, FL	Mixed
17	Volusia, FL	Classic
18	Clinch, GA	Mixed
19	Hall, GA	Occluded
20	Pickens, GA	Classic
21	Washington, IA	Mixed
22	Ada, ID	Classic
23	Kootenai, ID	Occluded
24	Kootenai, ID	Mixed
25	Kankakee, IL	Mixed
26	Brown, IN	Classic
27	Monroe, IN	Mixed
28	Porter, IN	Occluded
29	Johnson, KS	Mixed
30	St. Tammany, LA	Mixed
30	St. Tammany, LA	Occluded
30	St. Tammany, LA	Classic
31	Somerset, MD	Classic
32	Cumberland, ME	Occluded
33	Cumberland, ME	Mixed
34	Crawford, MI	Mixed
35	Beltrami, MN	Mixed
36	Crow Wing, MN	Classic
37	Dakota, MN	Occluded
38	Hubbard, MN	Mixed
39	Benton, MO	Mixed
40	Camden, MO	Mixed
41	Morgan, MO	Classic

Table 2. (*Continued*)

Label	County Name, State	Type
42	Stone, MO	Occluded
43	Taney, MO	Occluded
44	Flathead, MT	Classic
45	Gallatin, MT	Mixed
46	Pender, NC	Classic
47	Rolette, ND	Mixed
48	Dawes, NE	Mixed
49	Bernalillo, NM	Occluded
50	Colfax, NM	Mixed
51	Lincoln, NM	Classic
52	Albany, NY	Occluded
53	Orange, NY	Mixed
54	Suffolk, NY	Classic
55	Lawrence, OH	Mixed
55	Lawrence, OH	Occluded
56	Scioto, OH	Mixed
57	Comanche, OK	Classic
58	Oklahoma, OK	Mixed
59	Tulsa, OK	Mixed
60	Deschutes, OR	Classic
61	Josephine, OR	Mixed
62	Multnomah, OR	Occluded
63	Cameron, PA	Mixed
64	Chester, PA	Occluded
65	Monroe, PA	Classic
66	Washington, RI	Mixed
67	Meade, SD	Mixed
68	Pennington, SD	Classic
68	Pennington, SD	Occluded
69	Davidson, TN	Occluded
70	Putnam, TN	Mixed
71	Sevier, TN	Classic
72	Dallas, TX	Mixed
73	Harris, TX	Occluded
74	Travis, TX	Classic
75	Davis, UT	Classic
76	Salt Lake, UT	Occluded
77	Wasatch, UT	Mixed
78	Shenandoah, VA	Mixed
79	Benton, WA	Mixed
80	Chelan, WA	Classic
81	Ferry, WA	Mixed
82	Kittitas, WA	Occluded
83	Klickitat, WA	Occluded

Table 2. (*Continued*)

Label	County Name, State	Type
84	Spokane, WA	Classic
85	Burnett, WI	Mixed
86	Washburn, WI	Mixed
87	Wood, WI	Classic
88	Berkeley, WV	Classic
89	Kanawha, WV	Mixed
89	Kanawha, WV	Occluded
90	Fremont, WY	Mixed
91	Natrona, WY	Classic

create partnerships to ensure "safer" and "smarter" patterns of land development occur in and near wildland–urban interface areas. The remainder of this chapter is dedicated to exploring wildfire mitigation planning as an integral component of "safe smart growth" for wildland–urban interface communities. The following section provides an overview of the principles of "Smart Growth" and the very recent increased emphasis on "Safe Smart Growth." This is followed by a discussion of the eight core strategies that smart growth communities can and typically do use to reduce natural hazards losses, with commentary on lessons from the natural hazards research field on important steps to maximize the likelihood of successfully implementing safe smart growth. The final section concludes with thoughts on future opportunities for integrating Safe Smart Growth and promising areas for future research.

WHAT IS SAFE SMART GROWTH?

Smart growth is a phrase currently being used by a variety of governmental units (federal, state, and local), nonprofit and advocacy organizations (e.g., Smart Growth America, Urban Land Institute, National Home Builders Association, and Sierra Club) and foundations (e.g., PolicyLink and Robert Woods Foundation) that encompasses a greater emphasis on collaborative community and regional planning in the hopes of creating more economically, environmentally, and socially sustainable patterns of land development in the U.S. These organizations expect that smart growth initiatives can reduce a myriad of problems stemming from current patterns of sprawling development in the U.S., including: inefficient use of public infrastructure; traffic congestion; declining quality of life in urban environments; inadequate levels of affordable housing; loss and fragmentation of prime farmland and forestry areas; loss of important open space resources; loss of important functioning wetlands; declining surface and ground water quality from nonpoint source pollution, and increasing losses from natural hazards such as wildfire.

As one might expect, the definitions offered for what constitutes a ''smart growth'' program changes considerably depending on the mission of the organization being looked at (for an example of a typical range of smart growth interests see Smart Growth America's ten key steps in Table 3). For

Table 3. Smart Growth America's Ten Key Steps.

To achieve smart growth, communities should:

1. ***Mix Land Uses.*** New, clustered development works best if it includes a mix of stores, jobs and homes. Single-use districts make life less convenient and require more driving.
2. ***Take Advantage of Existing Community Assets.*** From local parks to neighborhood schools to transit systems, public investments should focus on getting the most out of what we've already built.
3. ***Create a Range of Housing Opportunities and Choices.*** Not everyone wants the same thing. Communities should offer a range of options: houses, condominiums, affordable homes for low-income families, and ''granny flats'' for empty nesters.
4. ***Foster ''Walkable,'' Close-Knit Neighborhoods.*** These places offer not just the opportunity to walk—sidewalks are a necessity—but something to walk to, whether it's the corner store, the transit stop or a school. A compact, walkable neighborhood contributes to peoples' sense of community because neighbors get to know each other, not just each other's cars.
5. ***Promote Distinctive, Attractive Communities with a Strong Sense of Place, Including the Rehabilitation and Use of Historic Buildings.*** In every community, there are things that make each place special, from train stations to local businesses. These should be protected and celebrated.
6. ***Preserve Open Space, Farmland, Natural Beauty, and Critical Environmental Areas.*** People want to stay connected to nature and are willing to take action to protect farms, waterways, ecosystems and wildlife.
7. ***Strengthen and Encourage Growth in Existing Communities.*** Before we plow up more forests and farms, we should look for opportunities to grow in already built-up areas, such as downtown business districts, Main Streets, and places with good public transit access.
8. ***Provide a Variety of Transportation Choices.*** People can't get out of their cars unless we provide them with another way to get where they're going More communities need safe and reliable public transportation, sidewalks and bike paths.
9. ***Make Development Decisions Predictable, Fair, and Cost-Effective.*** Builders wishing to implement smart growth should face no more obstacles than those contributing to sprawl. In fact, communities may choose to provide incentives for smarter development.
10. ***Encourage Citizen and Stakeholder Participation in Development Decisions.*** Plans developed without strong citizen involvement don't have staying power.When people feel left out of important decisions, they won't be there to help out when tough choices have to be made.

Source: Smart Growth America, Reprinted by permission.

example, the American Planning Association (APA) seeks to enhance the efficacy of community planning; while the U.S. Environmental Protection Agency (EPA) seeks to protect environmental quality – land, water, and air; the Urban Land Institute (1999) seeks to facilitate large-scale development; the National Association of Home Builders seeks to remove land use restrictions and increase affordable housing opportunities, and the Trust for Public Lands (2000) sees advantages for urban open space protection (Knapp, 2002). The somewhat amorphous or moving target character of smart growth efforts is not necessarily a bad thing given that the idea has only had about a dozen years or so to gel as an organizing concept for better community planning and development management.[4] In fact, the evolving nature of the concept bodes well for wildfire mitigation and loss reduction purposes as evidenced by recent efforts to make "safe growth" an integral part of the smart growth lexicon. Although not widespread at this time, one can find promising examples of efforts to link wildfire hazard mitigation (or safe growth) to Smart Growth through the efforts of the National Fire Protection Agency, the American Planning Association, and state planning and forestry programs such as Florida's Department of Community Affairs Local Mitigation Strategy, Oregon's Wildfire Hazard Mitigation Program, Wisconsin's Smart Forests for Smart Growth program, and Colorado's Department of Forestry.

The American Planning Association, the national professional organization for community planners, is helping to make connections between wildfire hazard mitigation planning and Smart Growth in several ways. The APA's Growing Smarter Legislative Guidebook provides model enabling legislation to make Smart Growth planning at local and regional levels easier to implement and has specific sections providing for natural hazard mitigation in local land use planning and development management (APA, 2002). In addition, over the last 3 years, APA has conducted several hazard mitigation training workshops entitled *Planning for a Disaster-Resistant Community*, which encompassed an adaptation of NFPA's training exercise for Firewise Communities with funding support from the Federal Emergency Management Agency. The APA has also released three important technical assistance publications that are very important for wildfire hazard mitigation planning: *Planning for Wildfires (2005)*, *Planning for Post-Disaster Recovery and Reconstruction (1999)*, and *Planning for Hillside Development (1996)*.[5] The *Planning for Wildfire* monograph provides model comprehensive plan elements, zoning, subdivision, and other code provisions as well as guidance on overcoming behavioral and institutional barriers to wildfire hazard mitigation implementation. The *Planning for Post-Disaster Recovery and*

Reconstruction guidebook emphasizes the "window of opportunity" that exists following a disaster in the wildland–urban interface to correct the wrongs of nonfirewise land development. It also emphasizes avoidance of future wildfire losses by quickly implementing appropriate mitigation through the disaster recovery and reconstruction processes. Across these three monographs, community planners and forestry planners are introduced to a myriad of "safe smart growth" strategies, including use of: hazards impact assessment to identify hazard reduction required for development approval; site-plan review processes to identify hazard reduction required for subdivision approval; low-density zoning of hazardous areas; overlay zoning with reduced density in hazardous areas; down-zoning to lower density in hazardous areas; hazardous development relocation planning; mandatory dedication of open space in hazardous areas for open space uses; cluster development to protect property and leaving the more hazardous areas undeveloped; density bonus in exchange for dedication of hazardous areas for open space uses; acquisition in "full fee" or "less than full fee simple" of land in hazardous areas; policies to locate public facilities and sensitive land uses outside of hazardous areas; urban services and growth boundaries; use of buffer zones and setback requirements; and impact fees or special assessment districts to finance hazard reduction.

The states of Wisconsin, Florida, Oregon, and Colorado stand out as models in their efforts to strengthen the connections between smart growth and wildfire mitigation. Wisconsin, Florida, and Oregon may offer the greatest potential for reducing wildfire hazards because the mitigation emphasis is gradually being integrated into their statewide land use planning requirements by statute, administrative code, and technical assistance.[6] Smart growth typically includes as a foundational element a participatory planning process that produces a shared vision for future development (see Chapter 9 by Ganz et al. and Chapter 10 by Stokowski for further discussions of community participatory planning in wildfire mitigation planning). This creates a unique opportunity to build a constituency of support for such ideas as steering development away from the highest wildfire hazard zones, or using parkland acquisition funds to acquire the highest wildfire hazard zones so that multiple community objectives can be accomplished simultaneously (e.g., open space preservation, recreation, environmental protection and hazard reduction). Equally important from a smart growth standpoint is the notion that "hazard mitigation" is not viewed as a hindrance to economic development but rather an essential element of a sustainable local economy: it creates a safer, more disaster-resilient community that is less susceptible to long-term economic shock and decline in the aftermath of a natural hazard event.

Under Wisconsin's Smart Growth legislation, enacted between 1999 and 2001, all Wisconsin towns, villages, cities, counties, and regional planning commissions must make land development decisions consistent with an adopted comprehensive plan by 2010. Wisconsin's comprehensive planning process encourages community leaders to join with citizens in exploring the existing condition of their community, imagining the community they want to become in the future, and developing a plan to bring that vision to life (WDNR, 2005). Wisconsin's Smart Forestry for Smart Growth program recognizes this period where all cities and counties are developing comprehensive plans as a unique opportunity to reduce Wisconsin wildland–urban interface fire hazards by providing examples of model wildfire hazard analysis, comprehensive plan element language (e.g. for natural-resource protection and housing elements), and model implementation language (see Table 4 for examples of model implementation language) (WDNR, 2005).

The State of Oregon has been a national leader in state growth management since the early 1970s, and remains at the forefront of smart growth in the 21st century. The 1973 growth-management legislation mandated all cities and counties to undertake local comprehensive planning that is consistent with 19 legislatively adopted state planning goals. Localities must adopt goals and policies in the local comprehensive plans that are in conformance with state goals addressing such matters as land use, urbanization, open spaces and natural resources,[7] forests and agricultural lands,[8] and natural hazards.The legislation also established a state agency, the Land Conservation and Development Commission, which must approve local plans to ensure they meet the state's requirements, including the designation of a 20 year "urban growth boundary" (UGB).[9] The UGB establishes strict lines between areas where urban and rural types of land use and development intensities will be permitted. Local zoning ordinances must be consistent with adopted local comprehensive plans as must capital improvement programming – sewer, potable water, school siting – in order to discourage inappropriate development uses and intensities. Agricultural, timber, and other rural land uses (e.g., very large lot residential such as 1 dwelling unit per 60 acres) are designated as permitted land uses beyond the UGB, significantly curbing suburban sprawl into wildland areas.[10]

Most importantly, from a wildfire mitigation standpoint is State Goal 7 (areas subject to natural disasters and hazards). It states that it is the goal of the State of Oregon to protect people and property from natural hazards by having local governments use adopted comprehensive plans (inventories, policies, and implementing measures) to reduce risk to people and property from natural hazards such as floods (coastal and riverine), landslides,

Table 4. Wisconsin's Smart Forestry for Smart Growth Fire in the Wildland Urban InterfaceModel Implementation Language.

Develop a forest fire information and education program to educate homeowners on forest fire issues and regulations important in protecting your community.
Develop standards for forest fire protection for developers wishing to build in your community. Require developers to submit a forest fire mitigation plan that addresses housing location, building materials, vegetation, emergency vehicle response access, fuel breaks, and water availability.
Assess current burning regulations and permit process and ensure that they support your forest fire mitigation and risk reduction goals.
Encourage forest management practices that sustainably meet the needs of current generations while providing adequate resources to meet the needs of future generations.
Plan for emergency fuel reduction treatments in the event of a forest insect or disease outbreak, storm damage, or forest fire event, which may result in large areas of dead, downed, or dying trees.
Incorporate goals, projects, policies, and actions of local, regional, and state forest master plans (county forest plan, state-owned, statewide forest plan, etc.) into your comprehensive plan.
Develop a coordinated forest fire emergency response dispatch, communication, and response infrastructure between municipal, county, state, and federal emergency response resources available at the local level.
Identify and maximize existing federal, state and local cost-sharing programs to prevent and suppress forest fires and encourage sustainable forest management.
Identify federal, state, and local level forest plans and encourage continued integration.
Identify transportation corridors for fire response and ensure adequate access.
Plan to accommodate fire response vehicles in design standards for the size, weight, and turning radius for driveways, access roads, bridges, turnouts, turnarounds, cul-de-sacs, and staging areas accordingly.
Ensure consistent and sequential patterns of road identification and ensure that all residential, commercial and public street signs and fire numbers are made from non-combustible, reflective materials that are easily visible from the street.
Develop a community evacuation plan in the event of a forest fire.
Properly plan for siting of new fire stations in conjunction with community needs and risk of forest fire.
Require all utilities to be underground in new developments to avoid additional hazard in the event of a forest fire.
Develop recommendations for the proper placement of propane tanks in forest fire-prone areas.
Determine the location and quantity of water supplies to ensure an adequate supply of water for the number of structures and wildland fuels in a specified residential area if threatened by forest fire.
In rural areas consider the need to plan for heliport locations, fire staging areas, and water access in the event of a forest fire.

Source: Wisconsin Department of Natural Resources (http://www.dnr.state.wi.us/org/land/forestry/SmartForestry/toolbox/issFireIMP.html), accessed March 30, 2005.

earthquakes and related hazards, tsunamis, coastal erosion, and wildfires. Localities must conduct natural hazard assessments and vulnerability analyses with full public participation on all natural hazards affecting the local jurisdiction. Based on those findings, local comprehensive plans must avoid development in hazard areas where the risk to people and property cannot be mitigated; and prohibit the siting of essential facilities, major structures, hazardous facilities, and special occupancy structures, as defined in the state building code (ORS 455.447(1) (a)(b)(c) and (e)), in identified hazard areas, where the risk to public safety cannot be mitigated (Oregon DLCD, 2002).[11]

The Oregon State Natural Hazard Mitigation Plan (2004) provides Oregon cities and counties with additional impetus to make Smart Growth connections to wildfire mitigation. The State Plan was adopted to come into compliance with the Disaster Mitigation Act of 2000, to keep the state of Oregon eligible for important pre- and post-disaster mitigation funds. The State Plan provides a new statewide hazard assessment that includes new wildfire hazard risk mapping (with plans to generate further highly detailed wildfire high hazard maps on a county by county basis). Normally, a local jurisdiction must properly respond to the State's Goal 7 natural hazard risk reduction mandate within 36 months after being notified by the state that new or updated information on a particular natural hazard exists. To help Oregon localities meet these obligations, the state has created a technical assistance manual, *Planning for Natural Hazards: Oregon Technical Resource Guide*, that encourages the use of a great many smart growth tools and techniques to reduce hazards, including cluster development ordinances, planned unit development zoning, land use acquisition programs such as purchase or transfer of development rights in high hazard locations, capital improvements programming, and hazard overlay zoning (Oregon DLCD, 2000).

An example of making wildfire-smart growth connections at the local level can be found in the City of Bend, OR, where its comprehensive plan includes policies to limit parking on narrow streets to ensure emergency vehicle access, shortened block lengths to insure greater street connectivity for emergency vehicle access and evacuation egress (as well as an enhanced pedestrian environment), and in areas where the natural slope exceeds 20%, the City may reduce minimum residential density or alternatively may require cluster development to improve natural vegetation and improve fire safety. Other opportunities to make better connections between wildfire mitigation and smart growth are also possible as more Oregon localities adopt local hazard mitigation plans to remain eligible for federal disaster mitigation funding under the 2000 DMA.[12]

Florida's state growth management system is on equal footing with Oregon as a national leader in smart growth. Although the history of Florida's state growth management efforts can also be traced back to the early 1970s, the most important elements were not put into place until the mid-1980s with the passage of the Omnibus Growth Management and Land Development Regulation Act of 1985 (Chapter 163 F.S., Part II).[13] The law requires all of Florida's 67 counties and 410 municipalities to adopt local comprehensive plans to guide future growth and development. Those local plans are reviewed by the Florida Department of Community Affairs to make sure they are consistent with the State Plan and the relevant Strategic Regional Policy Plan. The Florida State Plan has three goal sections that speak directly to the importance of natural hazard mitigation efforts: the Public Safety section (187.201 (6)), the Natural Systems and Recreational Lands section (187.201 (10)), and the Land Use section which, like Oregon, encourages the clear separation of urban and rural uses. Florida Administrative Code Rule 9J-5 establishes the minimum criteria for the preparation, review, and determination of compliance of local comprehensive plans and plan amendments consistent with the state legislation.

As in Oregon, local comprehensive plans must address several mandatory elements to guide future growth. In Florida, those elements include future land use, housing, transportation, infrastructure, coastal management, conservation, recreation and open space, intergovernmental coordination, and capital improvements programming. Localities may also chose to adopt additional plan elements including one focused on public safety from natural hazards, hazard mitigation plans, and disaster recovery planning.[14] Once local plans are approved by the state and adopted as code, localities are required to revise local land development regulations to implement those goals and policies in a manner that furthers the local comprehensive plan elements. Localities are required to "evaluate and appraise" (EAR) their local comprehensive plans at least once every seven years and use that process to determine what plan revisions are needed to better match current community priorities for growth and development. Localities in Florida are currently in the midst of the 2003–2007 EAR process, with the Florida Department of Community Affairs staggering due dates for localities' comprehensive plan submissions across the 4 years.

As in Wisconsin and Oregon, the comprehensive plan development and update process provides a unique opportunity to integrate wildfire hazard mitigation into the mainstream of Florida smart growth efforts. The Florida Department of Community Affairs is using extensive technical assistance programs to increase the use of comprehensive planning and land use strategies to reduce future damage to property and public facilities and to avoid development in hazardous areas in this current round of local comprehensive plan updates. This effort is coordinated with Florida's $9 million Local Mitigation Strategy program, which was established in 1998 to permanently reduce or eliminate risks to people and property from all natural hazards. These efforts include hazard summary profiles of existing and likely future hazard zones for all 67 counties (40 completed to date),[15] regional technical assistance workshops, best practice technical assistance guides, and 14 case study critiques of local hazard mitigation planning focused on how "well" or "poorly" those strategies have been integrated into local comprehensive plans (as well as suggestions for ways to better integrate hazards planning with local smart growth efforts). The recently released "*Wildfire Mitigation in Florida: Land Use Planning Strategies and Best Development Practices*," (Florida Department of Community Affairs, 2004) guide covers many of the same smart growth techniques found in the Oregon technical assistance guide, but provides much more detail in terms of case examples, model ordinance language, and detailed discussion of trade-offs of various approaches to make it far more useful for local planners and wildfire or forestry planners.

Another important state initiative is the Colorado Office of Smart Growth's Best Practices in Natural Hazards Planning and Mitigation guidebook (2003) that provides WWW links to model wildfire mitigation activities throughout the state. The handbook outlines model programs including Jefferson County's Wildfire Hazard Overlay District, Boulder County's Wildfire Hazard Identification and Mitigation System (WHIMS), and the City of Colorado Springs Wildfire Hazard Rating system. The Boulder County WHIMS program is completely integrated into the County's smart growth planning and development management system and is often cited as a national exemplar for wildfire hazard reduction efforts (Deyle, French, & Paterson, 1998).

The NFPAs efforts with the Firewise.org web page system and HFRA's (2003) Community Wildfire Protection Planning requirements also offer promising linkages between wildfire hazard mitigation planning and smart growth efforts, although that connection could be made far more strongly than has been accomplished to date. For example, while Firewise.org's Wildland/Urban Interface Hazard Assessment Training program (2002) provides important examples of how to assess wildfire risk, and suggests mitigation options that should be considered, it fails to show how the Village of Wellington, FL Wildfire Mitigation Plan can and should connect with the larger community smart growth objectives through its comprehensive plan (and all the plan elements that ensure implementation such as the future land use element, the transportation element, the public facilities element, the capital improvements element, and the parkland and open space elements).[16] While stand-alone wildfire mitigation plans can be helpful in minimizing individual risk for properties and improve suppression capabilities, they can also inadvertently create a "collective moral hazard" of encouraging more intensive development in fire-prone areas by making the area seem safer than it really is for more intensive land development (i.e., not steering or reducing overall development intensities within high hazard zones). Moreover, single hazard mitigation plans often fail to adequately consider the cascading impacts that can result from a single hazard event.[17] However, the hazard mitigation elements such as are found in local smart growth plan elements in California and Oregon typically consider a multitude of natural and technological hazards simultaneously along with several other important community planning objectives.[18] Another important reason to link hazard mitigation planning with smart growth planning is that smart growth planning uninformed by wildfire hazard mitigation planning may actually exacerbate wildfire disaster losses. Burby (2005) recently reported empirical evidence that smart growth "urban containment" programs actually increase disaster losses by forcing developers to look for more ecologically marginal and hazardous plots of land. But communities that combined smart growth "urban containment" efforts with natural hazards mitigation planning had the lowest per capita disaster loss ratios of all U.S. metro areas. The failure to consider multiple hazards simultaneously within the context of overall Smart Growth goals and objectives for a community may become even less problematic in the future as more and more localities adopt multihazard mitigation plans to remain eligible for disaster relief and mitigation funds as required under the federal *Disaster Mitigation Act of 2000* (DMA2K – P.L. 106–390).[19]

The lack of linkage between wildfire hazard mitigation planning and smart growth programming can also be found in recently released *Preparing a Community Wildfire Protection Plan Handbook* (2004) created by a consortium of groups including the Communities Committee, the Society of American Foresters, the National Association of Counties, the National Association of State Foresters, and the Western Governors' Association.[20] While the handbook is intended to provide communities with a concise, step-by-step guide to use in developing a Community Wildfire Protection Plan (CWPP), as recommended in the *Healthy Forest Restoration Act of 2003* (HFRA) (P.L. 108–148), it does so without ever suggesting that CWPP could be connected with community smart growth planning (e.g., comprehensive plans, sector plans, or neighborhood plans) and it does not even mention local planning and development management departments as desirable stakeholders that should be included in the CWPP planning process (which means smart growth approaches to wildfire mitigation are going to be very unlikely indeed).[21]

Platt (1999) concludes that wildfire disasters will inevitably continue to escalate in the U.S. largely because land use approaches such as those found in Smart Growth initiatives have, and continue to be, largely ignored in federal programs that deal with wildfire hazard mitigation in the wildland–urban interface. Not surprisingly then, most of the innovation found in Safe Smart Growth planning to reduce wildfire hazards is a product of state and local innovation. The following section reviews several of the major safe smart growth strategies that can, or actually have been used in states and localities to reduce wildfire risks in wildland–urban interface, and offers suggestions from the natural hazard mitigation literature on key steps to maximize the likelihood for success.

GETTING TO SAFE SMART GROWTH IN THE WILDLAND–URBAN INTERFACE

A review of local model wildfire mitigation programs identified by state foresters across the U.S. (Paterson, 2000) and the small but growing literature on safer smart growth (see, e.g., Deyle et al., 1998; Godschalk, 2002; and FEMA 364 n.d.) suggests that states and local governments rely on nine major strategies, to varying degrees, to support safe smart growth. Those strategies are:

1. *Land use planning and development management* – this involves mapping wildfire hazard zones (see Chapter 11 by Radke for a discussion of computer-based wildfire hazard mapping tools and Chapter 8 by Troy for discussion of statutory wildfire hazard mapping in California) and completing community vulnerability assessments that inform the community's smart growth planning process and results in a collaboratively created future land use map. The future land use map typically delimits both the "desired development zones" (places where growth will be encouraged) and "environmentally sensitive zones" (places where urban growth intensities will be discouraged – e.g., high hazard wildfire zones). The future land use map and smart growth plan then guide changes to local zoning, landscape, building, and subdivision regulations to implement those growth strategies.
2. *Avoiding the highest hazard areas* – this typically involves land acquisition strategies (e.g., transfer or purchase of development rights) that keeps new development away from the most hazardous locations (e.g., steep

slope, chimney, and ridges), special zoning overlays that regulate away inappropriate land uses from the high hazard zones, and relocating existing critical infrastructure (e.g., putting power lines below ground and protecting pump stations) and sensitive land uses (e.g., schools, assisted living, hospitals) to safer areas.

3. *Strengthening public and private buildings and public facilities* – these are steps taken by a community to retrofit homes, businesses, and community facilities (e.g., schools, park facilities, fire stations, city buildings etc.) to avoid or withstand ignition (e.g., roofing materials, decks, siding and soffits) through improved building, landscape changes, and infrastructure improvements.
4. *Conserving and restoring natural areas* – these steps encompass maintaining and enhancing the functions of forests by avoiding fragmentation, restoring fire regime ecosystem functions through prescribed burns and allowing natural burns to continue within limits (see Chapter 5 by Menning for a discussion of prescribed burning, including policy barriers to its implementation; see also Chapter 12 by Machin and Hentze for a discussion of the policy of allowing backcountry fires to burn naturally), and reforestation programs that gradually eliminate invasive exotic fire-prone vegetation/trees in favor of more ecologically appropriate indigenous vegetation and trees.
5. *Enhancing capacity to control natural hazards* – this encompasses structural approaches such as fuel breaks, fire breaks, forest thinning, and adding resources to enhance the wildfire suppression infrastructure and capacity within a region to reduce losses from wildfire events.
6. *Limiting public capital expenditures in environmentally sensitive zones* – this encompasses withholding public expenditures for improved road capacity, not allowing extensions or expansion of capacity for centralized potable water systems into rural land use areas, limiting the sizing and extension of centralized sewage transmission and treatment systems appropriately for urban and rural contexts, as well as limiting other public facilities that could induce development in high hazard areas.
7. *Making maximum use of fiscal incentives and disincentives* – this encompasses use of taxation policies to reduce inappropriate development in wildand–urban interface zones, such as impact taxes or special assessment fees to cover the costs of hazardous area fire-suppression capabilities in high hazard zones, tax breaks for homeowners and businesses undertaking and maintaining firewise landscaping and home conditions, and encouraging fire insurance rate structures that account for firewise development or the lack thereof.

8. *Communicating the wildfire mitigation message* – this encompasses educating homeowners, businesses and developers about firewise mitigation techniques; notifying the public about the existence of wildfire hazard areas prior to purchase (see Chapter 6 by Troy and Romm for a discussion of California's policies on real-estate transfer disclosure of wildfire hazard), and informing property owners about the consequences of locating in high hazard areas relative to fire-suppression capabilities that exist in the wildland–urban interface (e.g., volunteer fire departments verses full-time salaried fire departments).
9. *Regional collaboration and governance* – this encompasses regional collaborative, intergovernmental coordination and governance systems that are created to manage wildfire hazards that most often are "regional" in scope and complexity.[22]

As the above strategies make clear, communities at risk from wildfire hazards have many choices about how they will take steps to reduce wildfire risks. The question then is, given limited resources and time, which strategies are the best for a community to pursue? What strategies and elements of a smart growth and mitigation planning process will best maximize a communities chances of successfully implementing "safe smart growth" and help us to begin to reverse the national trend of escalating wildfire losses?

Fig. 3 provides insights as to what state foresters think are the most-effective avenues based on the author's national survey. What is most surprising from the survey results is that contrary to assertions by Sampson and DeCoster (2000) wildland–urban interface foresters are very supportive of land use planning and zoning approaches (which are typical components of smart growth programs in the U.S.). In fact, if one were to lump building code restrictions as part of land use and development management activities, this would be the singularly most-important tool that foresters across the nation think we must use to better reduce wildland–urban interface losses.

Additional insights about what strategies might work best to reduce wildland–urban interface wildfire losses can be gleaned from the smart growth and development management literature, and natural hazard mitigation planning literature. From the literature on the effectiveness of smart growth and development management, Paterson and colleagues (2005) report from a national expert panel reviewing tools and techniques to implement smart growth planning for natural resource and sensitive areas, that urban containment, land acquisition, comprehensive planning, planned unit development, taxation strategies, and regional coordination strategies are

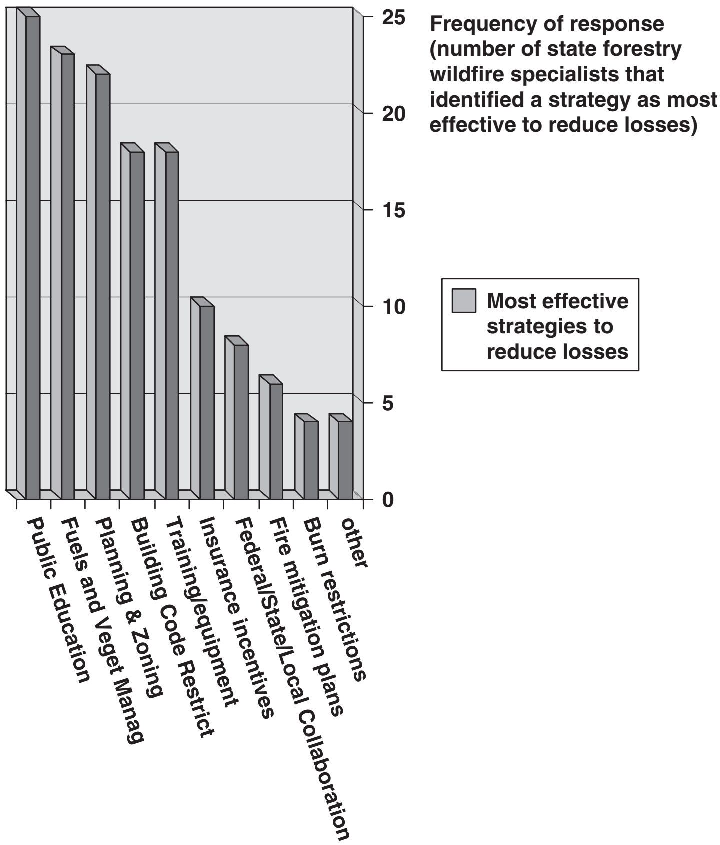

Fig. 3. Most-effective strategies to reduce losses from wildfire.

the most effective tools in a community's land use management tool kit (when used appropriately). In a national cross case analysis of 32 local sprawl mitigation or smart growth programs undertaken for the U.S. Congressional Research Service, Wilson and Paterson (2003) noted that the most successful smart growth efforts were those which (1) were tailored to the needs of the local population (showing an awareness of local cultural values and participatory involvement); (2) had well-defined goals but were able to adapt to changing circumstances; (3) used comprehensive or specific area plans to identify and delimit the desired development zones and protection zones; (4) were successful in coordinating among different levels of government, and working with nongovernmental and private-sector partners; and (5) successfully coordinated a broad range of development management tools and techniques in a complementary fashion.

Those findings are largely reinforced by over 30 years of natural hazards mitigation planning research reviewed by Olshansky and Kartez (1998). They note that smart growth or land use approaches to natural hazard mitigation are most likely to succeed when: (1) a community has strong hazard mitigation champions or advocates present (e.g., fire departments and forestry personnel) that keep hazard awareness and concern on the political radar; (2) there is strong and sustained collaboration and communication among key stakeholder groups and governmental levels (e.g., agency personnel, professional associations, and civic groups); (3) a feasible solution is known and efforts have been made to link the hazards solutions to solving other important community problems as is done in linking mitigation with smart growth (e.g., open space, environmental protection, evacuation capacity etc.,) so that the constituency support base within the community grows in size; and (4) a community capitalizes on a "window of opportunity" that may be opened when a large national wildfire disaster occurs which raises concern and salience in the community, or immediately following an actual wildfire event in one's own community.[23]

Critics of land use approaches or safe smart growth approaches to wildfire hazard mitigation may well scoff at some of these efforts because the adoption of smart growth strategies is one thing, while effective long-term implementation is quite another (see e.g., Cohen, 2000). Indeed, a study by de Jong (2003) that surveyed private-property compliance with California's statutes on firewise protections found that about 66% of the properties surveyed were noncompliant with requirements for landscape maintenance, and 75% of the lots had little or no defensible space. Further, Rice and Davis (1991) in evaluating land use approaches to wildfire mitigation noted problems as well in three case-study jurisdictions. They reported that the damage in all three counties was related to one of the following problems: (1) inadequate consideration of protection factors (i.e. language addressing fire-loss mitigation in general plans is weak); (2) disadvantages of small fire departments in dealing with developers and other units of local government (i.e. small fire departments have difficulty getting rigid regulations passed by elected officials); (3) heterogeneity in residential developments and in their susceptibility to control though planning (i.e. it is easier to control the developments because of the required stages of review); and (4) conflicting interests among homeowners, developers, and local governments (i.e. homeowners build in the intermix based on promises, that are often not enforced by developers or local government).

Yet, problems with long-term implementation of government programs or lack of compliance with governmental regulations are not new, and possible solutions to such problems have been found through research. The previous section, citing the work by Wilson and Paterson (2003), rebuts that contention in large part because their study only looked at smart growth programs that had already proven their worth through substantial longevity. In addition, research by Deyle et al. (1998) working from a national survey of local building code compliance, found that effective enforcement is most likely to occur when an agency employs a facilitative enforcement approach with (1) an adequate number of technically competent staff; (2) strong proactive leadership from government; (3) adequate legal support for enforcement; and (4) a consistently strong effort to check building and development plans and provide technical assistance to the development community. Thus, ways to effectively stem slippages in code enforcement are known and may be used to stem such compliance shortfalls. Moreover, although Rice and Davis (1991) found problems in their three-county study of land use approaches to wildfire mitigation, they ended their study by concluding that where land use planning was effectively used, not a single house was lost. Thus, while there will always be variation in the consistency of implementation, it certainly does not mean federal, state, and local officials should give up on efforts to facilitate more widespread adoption and use of safe smart growth principles, it simply means we must make sure all the tools for successful implementation are available to make success more likely in the long run.

CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

This chapter has presented information suggesting that losses from wildfire events in the U.S. will only continue into the future unless significant steps are taken nationally to reduce the number of people and the amount of property being placed at risk in the wildland–urban interface (Platt, 2001). One important step to reverse those losses is linking wildfire hazard mitigation planning to state and local smart growth. Unfortunately, very little research, in terms of both case study and cross sectional designs, have been undertaken to better understand the factors that predict local success in make those linkages. Important areas for future research include: (1) evaluation of urban growth boundaries and urban services boundaries in reducing pressure for "buckshot sprawl" in the wildland–urban interface; (2) evaluation of "rural by design" approaches for ex-urban and near-urban development that creates new ''regional firewise land development patterns'' that keep wildland fire hazards to a minimum while respecting small-town values and traditional rural land development patterns; (3) evaluation of and pilot programs for regional ''safe smart growth'' programs that explore new institutional structures and arrangements for more effective wildland–urban interface management; and (4) research that helps explain why some localities are true leaders and others significantly lag in reducing significant wildfire risks (building on the existing natural hazards literature [Mileti, 1999] as a reference point for future investigations). In conclusion, while this chapter has noted some promising activities that may jump start more widespread ''safe smart growth'' in the U.S., it remains unclear whether the necessary linkages between natural resource managers, community planners, and community leaders will be accomplished in enough time to shift wildland–urban interface patterns from ''dumb growth'' to ''safe smart growth'' in order to stem the tide of escalating U.S. wildfire losses.

NOTES

1. National Fire Protection Association (NFPA) data indicate that wildfires destroyed approximately 9,000 homes between 1985 and 1994 in the United States. In 2002, a year when Arizona, Colorado, and Oregon had their largest wildfires on record, wildfires burned 835 homes. In 2003, wildfires destroyed an additional 4,000 homes.

2. Moreover, the wildfire events with the greatest number of structural losses included not only the western states such as California, Nevada, Arizona, Montana, and Colorado, but also Wisconsin, Michigan, Illinois, Oklahoma, Texas, Florida, and South Dakota (wildfire events with losses of 25 structures or more).

3. In 1999–2000, the author surveyed state forestry personnel knowledgeable on wildland urban interface hazards for their state (one state forestry respondent to represent the state of knowledge per state). Using Dillman's Total Survey Design Method (1978) the author obtained a 95% response rate (Alaska and Delaware were non-response states).

4. According to Godschalk (2000) smart growth started as an important state and local movement in the early 1990s as new programs developed in Maryland, Delaware, Tennessee, and Pennsylvania that built on previous growth management programs. Particularly notable is Maryland, which added strong state-funding incentives to combat sprawl. By 2000, at least half of the state-of-the-state addresses by governors in that year discussed smart growth with gubernatorial support growing in Arizona, Colorado, Georgia, Illinois, Minnesota, North Carolina, Utah, and Wisconsin, and legislative activity in California, Colorado, Hawaii, Iowa, Kentucky, Nevada, New Mexico, Ohio, and Oklahoma.

5. Planning Advisory Service Reports are the American Planning Association's most important technical assistance program with over 450 technical reports issued to date.

6. Burby et al.'s (1997) multi-state assessment of local planning for natural hazards mitigation found, in comparing states with mandated local planning against those without, that mandatory state/local growth management programs improve the quality of both local plans and development management efforts.

7. For example, the implementation section of this state goal encourages local, regional, and state governments to investigate and utilize fee acquisition, easements, cluster developments, preferential assessment, development rights acquisition, and similar techniques to implement this goal.

8. Goal 4, Forest Lands, requires local jurisdictions with such lands to adopt regulations that minimize wildfire hazards when permitting new dwellings and structures, including setbacks, roads standards, fuel breaks and use of fire retardant roofing materials.

9. Localities that fail to bring plans and ordinances into conformance with state statues and regulations pertaining to local planning requirements may lose state revenues from gas, cigarette, and liquor taxes.

10. In theory this should help limit some types of wildland urban interface zones being created (or at least the magnitude of the interface zone hazards), to date however the author is unfamiliar with any empirical assessments of this issue.

11. Following the 1990 Awbrey Hall Fire in central Oregon, the Oregon legislature adopted laws providing statutory authority to localities to designate wildfire hazard zones which make elements of the state building code mandatory (provided the locality has a life safety or building code in place). This was necessary because some Community Residential Associations required the use of "flammable" roofing materials as part of the binding covenants on private homes within the subdivision. The state statutes overrule such covenants requiring local use of nonflammable roofing in wildfire hazard zones. In addition, property owners in designated wildfire hazard areas have two years to make their property less prone to loss or damage from wildfires. Property owners who fail to mitigate are subject to a maximum of $100,000 liability for the cost of suppressing fires which start on their property (and spread due to their noncompliance).

12. Although great potential exists for making "safe smart growth" connections for wildfire mitigation in Oregon, there is also cause for some pessimism. The State Natural Hazard Mitigation Plan is largely silent on land use approaches to reduce hazards; it simply notes the state growth management system offers opportunities to reduce hazards rather than explicitly endorsing land use and other smart growth approaches (Oregon NHMP, 2004). The State's highly profiled and award winning Josephine County Fire Plan also largely fails to consider land use approaches. There are virtually no connections to the 2002 update of the Josephine County Comprehensive Plan (Oregon PDRR, 2002; Josephine County Integrated Fire Plan, 2004; Josephine County Comprehensive Plan Update, 2002).

13. The key sections of the Florida Statutes that define the state growth management system include: Chapter 187, the State Comprehensive Plan; Chapter 186, Strategic Regional Policy Plans; Chapter 163, Growth Management Act; Chapter 380, Developments of Regional Impact and Areas of Critical State Concern.

14. This refers to a safety element for the protection of residents and property of the area from fire, hurricane, or manmade or natural catastrophe, including such necessary features for protection as evacuation routes and their control in an

emergency, water supply requirements, minimum road widths, clearances around and elevations of structures, and similar matters (section 163.377(7)(h) and (l) F.S.).

15. The profiles will identify the predominant hazards in these communities, the hazard mitigation principles that are in place, and recommend additional hazard mitigation principles that could be incorporated into the comprehensive plans to reduce hazard vulnerability and risk. These profiles will also contain suggestions on how the current local mitigation strategies could be enhanced to support long-range planning efforts through additional data or information strategies (FL DCA, 2005).

16. The primary reason for developing a Hazard Mitigation Plan is to reduce community exposure to natural hazards by taking proactive, pre-disaster planning steps to limit development in high hazard sensitive areas, particularly areas subject to high wildfire hazards. Stand alone hazard mitigation plans often fail to make a connection to land use choices (Burby et al., 1999).

17. That lesson was hard learned in several California communities that experienced floods, landslides and mudslides triggered in large part from watershed scale changes from wildfire.

18. See, for example, the Boulder County, CO Natural Hazards Comprehensive Plan Element at http://www.co.boulder.co.us/lu/bccp/nat_haz.htm.

19. See section 44 CFR Part 201- Mitigation Planning Interim Final Rule published February 26, 2002; and the Multi-Hazard Mitigation Planning Guidance Under the Disaster Mitigation Act of 2000 published by FEMA March 2004.

20. Daly (2004) made a similar critique: "When a collaborative process is begun and communities study local forest stand conditions, watersheds, threatened and endangered species, and other critical resources, they are almost certain to identify the need for ecosystem management and restoration work which goes beyond hazardous fuels treatment. CWPP planning should not be a process in isolation, but should feed into other relevant federal, state, and local planning activities."

21. While the minimum requirements for a CWPP under HFRA are: (1) a CWPP be collaboratively developed by local and state government representatives, in consultation with federal agencies and other interested parties; (2) a CWPP must identify and prioritize areas for hazardous fuel reduction treatments and recommend the types and methods of treatment that will protect one or more at-risk communities and essential infrastructure; and (3) a CWPP must recommend measures that homeowners and communities can take to reduce the ignitability of structures throughout the area addressed by the plan, there are no good reasons to restrict the range of planning options in the handbook to such a limited set of mitigation examples. "Informed choice" would logically call for the broadest range of ideas to pick and choose from for wildfire risk reduction.

22. The multiplicity of federal, state, and local governmental jurisdictions with land use authority and management responsibilities in the wildland urban interface zone creates significant institutional barriers to hazard reduction effectiveness.

23. Other factors noted include adequate staffing resources for the planning process and implementation of solutions, community wealth and resources, political culture supportive of a public common good perspective as opposed to individualized private property rights, and mandates or assistance from state and federal government (Olshansky & Kartez, 1998Ohlshansky & Kartez, 1998).

REFERENCES

American Planning Association. (1996). Planning for hillside development. In: R. B. Olshansky (Ed.), *PAS Report 466*. Chicago, IL: Planners Press.

American Planning Association. (1999). Planning for post-disaster recovery and reconstruction. In: J. Schwab, et al. (Eds), *PAS Reports 483/484*. Chicago, IL: Planners Press.

American Planning Association. (2002). *Growing Smart^{SM} legislative guidebook: Model statutes for planning and the management of change*. In: S. Meck (Ed.). Chicago, IL: Planners Press.

American Planning Association. (2005). Planning for wildfire. In: J. Schwab & M. Stuart (Eds), *PAS Reports 529/530*. Chicago, IL: Planners Press.

Burby, R. J. (2005). Have state comprehensive planning mandates reduced insured losses from natural disasters? *Natural Hazards Review*, *6*, 67–81.

Burby, R. J., May, P. J., Berke, P. R., Dalton, L. C., French, S. P., & Kaiser, E. J. (1997). *Making governments plan: State experiments in managing land use*. Baltimore, MD: Johns Hopkins University Press.

Cohen, J. D. (2000). Preventing disaster: Home ignitability in the wildland–urban interface. *Journal of Forestry*, *98*(3), 15–21.

Daly, C. (2004). Implementation of the Healthy Forests Restoration Act and Community Wildfire Protection Plans, Testimony by Carol Daly, President, Communities Committee and Member, Society of American Foresters Subcommittee on Forestry, Conservation, and Rural Revitalization Senate Agriculture, Nutrition, and Forestry.

Davis, J. B. (1990). The wildland–urban interface: Paradise or battleground? *Journal of Forestry*, *88*(1), 26–31.

De Jong, L. (2003). Improving fire hazard assessment in South Lake Tahoe, CA. *Fire Management Today*, *63*(2), 35–38.

Deyle, R., French, S., & Paterson, R. (1998). Hazard assessment: The factual basis for planning and mitigation. In: R. Burby (Ed.), *Cooperating with nature: Confronting natural hazards with land-use planning for sustainable communities*. Washington DC: Joseph Henry Press.

Dillman, D. A. (1978). *Mail and telephone surveys, the total design method*. New York: John Wiley & Sons.

Firewise.org. (2003). *Wildland–Urban Interface Hazard Assessment Training*. FWC-624-03-CD. Washington DC: Firewise.org.

Florida Department of Community Affairs. (2004). *Wildfire Mitigation in Florida: Land Use Planning Strategies and Best Development Practices*. Retrieved September 25, 2005, from http://www.dca.state.fl.us/fdcp/DCP/publications/index

Godschalk, D. (2000). Smart growth efforts around the nation. *Popular Government*, *66*(1), 12–20.

Godschalk, D. (2002). Urban hazard mitigation: Creating resilient cities. Plenary paper presented at the Urban Hazards Forum, John Jay College, City University of New York, January 22–24, 2002.

Josephine County Oregon. (2004). Josephine County Integrated Fire Plan. Prepared By the Program for Watershed and Community Health, University of Oregon. Retrieved June 23, 2006 from http://68.185.2.151/website/jcifdocs/jcifp.pdf

Knapp, G. (2002). *Talking Smart in the US*. National Center for Smart Growth, The University of Maryland, Working Paper, March.

Mileti, D. (1999). *Disasters by design: A reassessment of natural hazards in the United States*. Washington, DC: Joseph Henry Press.

National Oceanic Atmospheric Administration (NOAA). (2005). Billion dollar losses US Weather Diasters, Retrieved Jan 15, 2005, from http://www.ncdc.noaa.gov/oa/reports/billionz.html

Olshansky, R. B., & Kartez, J. D. (1998). Managing land use to build resilience. In: R. Burby (Ed.), *Cooperating with nature: Confronting natural hazards with land-use planning for sustainable communities*. Joseph Henry: National Academy Press.

Oregon Department of Land Conservation and Development (DLCD). (2000). *Planning for natural hazards: Oregon technical resource guide*. Retrieved December 15, 2005, from http://www.lcd.state.or.us/LCD/HAZ/publications.shtml#Planning_for_Natural_Hazards_Oregon_Tech_Resource_Guide_2000_

Oregon Department of Land Conservation and Development (DLCD) (2002). *Statewide planning goals*. Accessed on January 1, 2005 at: http://www.lcd.state.or.us/LCD/goals.shtml#Statewide_Planning_Goals

Paterson, R., Handy, S., Bhat, C., Kockelman, K., Song, J., Rajamani, J., Jung, J., Banta, K., Desai, U., & Waleski, J. (2005). *Techniques for Mitigating Urban Sprawl*. A Final Report to the Texas Department of Transportation, Center for Transportation Research, University of Texas at Austin, Austin TX, Project 4420-2.

Patterson, W. A. (2001). What are the trends in wildland fires and what is the future for increased fires/risk? Paper presented at Natural Disasters Roundtable Forum on Urban/Wildland Fire, January 26, 2001, Washington DC, National Academy Press.

Platt, R. H. (1999). The bay area: One disaster after another. In: R. Platt (Ed.), *Disasters and democracy: The politics of extreme natural events* (pp. 176–241). Washington DC: Island Press.

Platt, R. H. (2001). To burn or not to burn, summary of the forum on urban/wildland fire. The National Academies Natural Disasters Roundtable, January 26, 2001, Washington, DC. National Academy Press.

Rice, C. L., & Davis, J. B. (1991). Land-use planning may reduce fire damage in the urban–wildland intermix. Gen. Tech. Rep. PSW-127. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Sampson, N., & DeCoster, L. (2000). Forest fragmentation: Implications for sustainable private forests. *Journal of Forestry*, *98*, 4–8.

The Trust for Public Land. (2000). About TPL. Retrieved January 4, 2004, from http://www.tpl.org/tier2_sa.cfm?folder_id = 170

Urban Land Institute. (1999). *Smart growth: Myth and fact.* Retrieved September 25, 2004, from http://www.smartgrowth.org/information/aboutsg.html

Wilson, R. H., & Paterson, R. G. (2003). *Innovative initiatives in growth management & open space preservation policies*. LBJ School of Public Affairs, Policy Research Project Report, University of Texas: LBJ School of Public Affairs, Monograph Number 149.

Wisconsin Department of Natural Resources. (2005). Smart Forestry for Smart Growth: Assessment section of Planners Toolbox. Retrieved December 5, 2005, from http://www.dnr.state.wi.us/org/land/forestry/SmartForestry/toolbox/assessment.html

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CHAPTER 5

PRACTICAL AND INSTITUTIONAL CONSTRAINTS ON ADOPTING WIDE-SCALE PRESCRIBED BURNING: LESSONS FROM THE MOUNTAINS OF CALIFORNIA

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> Fire, as a critical natural process, will be integrated into land and to resource management plans and activities on a landscape scale, and across agency boundaries. (NWCG, 2001)
>
> The actual goal of fuels-management projects should be the reduction of potential fire behavior and effects, not the simple reduction of fuels. (Stephens & Ruth, 2005)

INTRODUCTION

Forests too thick with fuels that are too continuously spread to resist fire are common throughout the west. After a century or more of actively working to suppress fire across the landscape, we now recognize that fire is a part of our forests, shrublands, and range, and that it will come whether we wish it or not. At last, managers must realize forests cannot be fire-proofed

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(DellaSala, Williams, Williams, & Franklin, 2004). We must work with fire rather than against it.

We often think about reintroducing fire purely in physical terms: can prescribed fire be brought back at a low enough intensity and severity that it can return to a natural role in an ecosystem? What are the physical effects on fuels, vegetation structure, and tree mortality? How does prescribed fire affect regeneration of vegetation and fuels and how might it alter ecosystem trajectories? All of these are excellent and important questions. In many cases, however, practical, societal, and institutional roadblocks render such questions moot.

Obvious to many are the economic costs involved in implementing a prescribed fire program. Costs may be calculated on a per-acre basis and compared to the costs of fighting unexpected wildfires. More subtle are other factors that can affect whether flame ever meets fuels in a controlled environment: smoke production, changes to aesthetic quality, impacts on tourism, perceptions of risk to homes, agency funding and reimbursement, and a lack of information about the whole range of hazards, actions and their consequences.

And thus, in the midst of this confusion of confounding factors, managers are forced to address reality rather than simple ideals about the physical environment. They must overcome the traditional notion that management decisions derive from "sound science" or "good economics" and that public preferences and opinions are uniform and can easily be "overcome with more facts, logic, and rational explanations." (Shindler, Brunson, & Stankey, 2002)

In the remainder of this introduction, I examine western U.S. fire policy and history and build a context for our current fuels conditions and fire hazards. In the next segment of the chapter, "Reasons for bringing fire back," I map out the major reasons for bringing controlled fire back into ecosystems from which it has been excluded. A discussion of the constraints on restoring fire follows in the chapter's third section, "Facing constraints ...." In the last major section of the chapter, "When and where fire should be brought back ...," I discuss the physical and social conditions under which it seems reasonable and likely that controlled fire could be reintroduced.

Western Fire History: Suppression and Its Consequences

In order to examine the paradox of fire returning to the landscape to help stave off the reoccurrence of unnatural and severe fires, we first need to examine the history that has led to this situation. In the American west, fire has been a dominant agent of change in many forest types. Tree ring and fire scar analysis in the southern Sierra Nevada reveal a fire regime that burned in the mixed conifer-sequoia forest on an average of every 8–32 years (Caprio & Swetnam, 1995; Skinner & Chang, 1996). During recent centuries, fires in the montane forests in the Sierra Nevada typically were frequent, low-severity fires with occasional moderate and high-severity patches (Stephenson, Parsons, & Swetnam, 1991).

Humans have influenced these cycles with a century or more of fire suppression (Baker, 1993; Erman & Jones, 1996; McKelvey & Buse, 1996; Skinner & Chang, 1996). The U.S. Army began putting out fires while patrolling newly founded parks in the late 19th century (Stephens & Ruth, 2005). Passive suppression occurred through the reduction of fine fuels by extensive grazing on western lands. Meanwhile, huge, extremely severe fires that raged in the upper Midwest in 1871 and the northern Rockies in 1910 helped to convince the public that fires were a serious danger, a kind of "evil" force (Dombeck, Williams, & Wood, 2004). This attitude that fire was a dangerous entity beyond human influence was prevalent despite the fact – as we understand it now – that in many of those cases much of the fire was due to intensive harvesting that left an overabundance of litter and debris on the ground (Dombeck et al., 2004). That human activity helped to cause fire was not understood. Fire itself was seen as the culprit and therefore the solution was to stop fire (see Chapter 2 by Kennedy for a further discussion of the institutional history of fire suppression in the U.S.).

Indeed, human activities, such as logging and fire suppression, in addition to a changing climate, have dramatically affected forest structure and pattern over time (Erman, 1996; Kline, 2004; Savage, 1994). Over the last century of fire suppression, for example, more white firs have grown into the Sierra Nevadan Mixed conifer forest at the expense of large pines (McKelvey & Johnston, 1992). Fires have generally become more frequent and extensive and severity is often higher than it was historically (Kline, 2004; Stephenson et al., 1991). Changes in the fire regimes of the Sierra Nevada, such as return intervals, extent, and intensities of fire, have increased forest density, species composition, and structural characteristics (Ansley & Battles, 1998; Johnson, Sessions, & Franklin, 1996; McKelvey & Buse, 1996; McKelvey et al., 1996; Roy & Vankat, 1999; Skinner & Chang, 1996). In a circular fashion, these changes in forest conditions have led to further changes in fire.

Interestingly, at least from our modern perspective, prescribed fire was considered as a solution to increasing fuel loads created by the suppression of fire. Comparisons of suppression versus light underburning were conducted in the early 1920's and complete exclusion of fire was considered the more effective treatment (Stephens & Ruth, 2005).

The tide began swinging in the opposite direction with publication of the Leopold Report in 1963 (Leopold, Cain, Cottam, Gabrielson, & Kimball, 1963; Stephens & Ruth, 2005). This landmark investigation reported that the exclusion of fire was hurting wildlife populations by negatively affecting their habitat. About the same time, controlled burning began informally in Sequoia National Park (Biswell, 1989).

Meanwhile, fire extent and causes changed markedly from 1940 to 2000 (Stephens, 2005). Many large fires now were suppressed only by changes in weather conditions (DellaSala et al., 2004). And despite putting more money and manpower into the problem, hectares burned and suppression costs both climbed from 1994 to 2002 (Dombeck et al., 2004). Unfortunately, suppression often led to unusually large and frequently severe fires. The big fire years of 1988, 1994, 2000, and 2002 were wake-up calls that fire suppression wasn't working (Dombeck et al., 2004). And the pattern may extend into the future. Despite improved fire-fighting techniques, size and extent of fires in CA are expected to increase markedly (Fried, Torn, & Mills, 2004; Stephens & Ruth, 2005). This pattern has held true in other regions of the world where suppression also was the primary policy of "dealing" with the problem of fire (Bond & Archibald, 2003).

The Current Context

Suppression has brought a number of changes to fire regimes on Western lands; fire scientists are concerned about the risk of severe and uncharacteristic fire due to the build-up in volume and continuity of fuels (Erman, 1996; Keeley & Fotheringham, 2001a). Fuel loads have accumulated, increasing risk of high-intensity, high-severity stand-replacing fire (Franklin & Agee, 2003). Similarly, ecologists are concerned that wildlife and biodiversity are negatively affected and that forests are perturbed to the degree that many species may decline due to unnatural succession (Erman, 1996; Stephenson, 1999). As a result, a number of ecologists and fire scientists recommend treating forests to achieve the twin goals of restoring more natural conditions and reducing severe fire hazards (McKelvey et al., 1996; Parsons, 1995; Stephenson, 1996; Stephenson, 1999).

Despite a flurry of recent policy development and legislation such as the National Fire Plan (NWCG, 2001; U.S. Department of Agriculture and U.S. Department of Interior (USDA-USDI), 2000) and President Bush's Healthy Forests Initiative of 2002 that became the Healthy Forests Restoration Act of 2002, there remains no comprehensive policy for dealing with fuels and fire (Franklin & Agee, 2003; O'Laughlin, 2005a, 2005b; Stephens & Ruth, 2005). The Forest Service's goal of reducing fire hazards on 1.2 million ha of forests using mechanical treatments and fire has suffered slow progress (GAO, 2003; Stephens & Ruth, 2005).

Meanwhile, as each chapter in this volume attests, the problem of fire in the wildland–urban interface (WUI) is escalating. An expanding population and WUI build-out are major factors in the risk of severe fire (Dombeck et al., 2004). Costs associated with fire in these volatile zones are higher than in wildlands where fewer structures and human lives are at risk (Yoder, 2004). In 2003, U.S. federal agencies spent over a billion dollars fighting fires across the country (GAO, 2004).

The Problem of Suppression Rather than Prevention

Success in fire management has long been measured in terms of the number of fires put out and up to 98% are often extinguished (Dombeck et al., 2004). Unfortunately, eliminating many small fires does not always work in our favor. Fires naturally burn fuels away; their absence leaves fuels. And so, fire suppression leaves fuels on the ground to accumulate.

The lack of many small disturbance events may result in homogenization of forest conditions. Disturbances, as contrasted with "catastrophes," are periodic events that are fundamental in shaping the biological characteristics of ecosystems (Agee, 1993; Sousa, 1984). Outside human influence, forests are subject to disturbances that range from small, isolated, discontinuous, and frequent events, to large, extensive, continuous, and infrequent events (Sousa, 1984). If a forest were viewed over time, one might experience these small, frequent disturbances as a kind of background flickering in the overall matrix of the forest. Such local disturbances shape and are shaped by local community structure and ecosystem processes. In contrast, larger disturbances may cover vast areas, occur suddenly, and then not reoccur for a considerable time. These flashes of disturbance may be native to a forest system; over time, forest structure, pattern, and composition may adapt to reflect the combined effects of the flickering and flashing of the disturbances that affect them. In some cases, however, forests have changed dramatically with human influence.

When fuels, ignitions, and severe conditions synchronize the result is often large, severe fires, uncharacteristic of the historic fire regime. Thus, fire suppression often leads to homogenization of forests; forests lacking patchiness and complexity are more likely to burn extensively (Dombeck et al., 2004; Martin & Sapsis, 1991).

We have learned the question is not *whether* fire will burn but *when*, and with what consequences (Dombeck et al., 2004). The solution is to help control the conditions under which fire is reintroduced into systems. This strategy is finally finding its way into national policy. The National Fires Plan took a step in this direction by suggesting a change from being reactive to being proactive: agencies are supposed to change from fighting big fires to preventing big fires (GAO, 2002; NWCG, 2001). The Forest Service, in reply to a GAO investigation of budgetary problems relating to fire, indicated that the best way of reducing costs of suppressing fires was by pre-treating fuels (by mechanical means or fire) prior to the onset of the very extensive and expensive fires themselves (GAO, 2004). Similarly, the 10 year Comprehensive Strategy put together by the Western Governors' Association (WGA, 2001) laid out a series of goals, including improving *both* prevention and suppression, reducing hazardous fuels prior to fire, and promoting community assistance all while restoring fire-adapted ecosystems (see Chapter 9 by Ganz et al. for further discussion of this plan).

A Word About Words – Risks and Hazards

Words such as risk, hazard, and catastrophe not only describe conditions and events but convey social values and judgments as well (O'Laughlin, 2005a, 2005b). In the literal sense, risk of fire is simply the likelihood that fire will occur; the word indicates nothing about the kind or extent of fire, nor of the hazards of the conditions and ignition (Hardy, 2005). In this light, all fire, even prescribed, is a risk and so the term carries negative connotations (Hardy, 2005). Similarly, what was termed "catastrophic" fire is now termed "uncharacteristic" to indicate that it falls outside a historic range, but without ascribing social value to the event. This helps clarify the nature of the event and its effects. A large fire, for example, could be socially catastrophic, yet still be within a historic range of occurrence (Hardy, 2005). As a result, it is useful to apply the word hazard when discussing fuels as this implies a state or precondition for a specific process such as a fire

(Hardy, 2005). A physical state – such as fuels conditions – can be measured without ascribing value to the measurement.

REASONS FOR BRINGING FIRE BACK

There is broad agreement that treating fuels should focus both on restoring more natural conditions and reducing severe fire hazards (GAO, 2002; McKelvey et al., 1996; NWCG, 2001; Parsons, 1995; Stephens & Ruth, 2005; Stephenson, 1996; Stephenson, 1999). Let us examine these goals one at a time. Doing so will allow us to examine whether and how fire may be restored to the landscape in a controlled fashion.

Restore Natural Cycles, Structure, Function, and Habitat

> … [We] must investigate how natural systems recover from disturbance … such as natural and human-influenced fire, vegetation manipulation (pre- and post-European settlement) … Eliminating natural disturbances in general, and fire in particular, has caused unanticipated and undesirable changes to the ecosystem. Better knowledge of ecosystem structure and function is necessary to better understand how natural disturbance processes can be mimicked through innovative management. (Centers for Water & Wildland Resources, 1996)

Neither nature nor society is static. Changing values and perceptions affect the way we interact with our environment. It may be argued that resource management is going through an era of fundamental change in perspective, from focusing on a rigid perception of the ''balance of nature'' to a more dynamic view of the ''flux of nature'' (Bond & Archibald, 2003). This social understanding that conditions change and that variability is important is widespread (Agee, 2003, 2004; Fried et al., 2004; Stephens & Ruth, 2005). Across landscapes where flames have long shaped patterns of vegetation, fire is often the best solution for maintaining biodiversity and ecosystem function (Yoder, 2004). Frequent, small fires also help maintain heterogeneity in vegetation. Shifting mosaic models of landscape patterns predict that this diversity at the landscape level is critical to regional ecological stability (Sousa, 1984; Urban, O'Neill, & Shugart, 1987). Fuels reduction programs aim to restore some semblance of these natural cycles, including ecosystem function and structure, maintenance or improvement of habitat, and increases in the heterogeneity in the environment.

Considerable uncertainty remains about what the effects of restoring fire will be. While fire suppression has dramatically affected vegetation throughout the west, little is known about what happens to ecosystem trajectories when a disturbance with a regular frequency is excluded from a system for a considerable length of time (Greenlee & Langenheim, 1990). It is also not known what occurs when a disturbance long withheld from a system is reintroduced (Covington & Moore, 1992). And, of course, the specter of climate change muddles the picture considerably (the subject of climate change and wildfires is discussed further in Chapter 13 by Keeton et al.).

Reduce Fuels and Fire Behavior

> Although not guaranteed, the expectation is that fuel treatments over the long term will result in lower fire suppression and post fire restoration costs, less smoke, less wildfire-related property damage, and fewer lost socioeconomic and ecological benefits. (Kline, 2004)

The well-intended but often misguided policy of suppressing fires – natural or human-caused – has led to dangerous build-up of fuels (GAO, 2002; Stephens & Ruth, 2005). These fuels are found on the ground, scattered over the surface, rise in ladders, and are arrayed in the air as crown fuels (Menning & Stephens, in press; Stephens & Ruth, 2005).

While reducing fuels is often a primary goal of fuels treatment plans (Dombeck et al., 2004; GAO, 2003; NWCG, 2001), it has recently been argued that a far better goal is to reduce the potential behavior and effects of fire (Stephens & Ruth, 2005). This may seem a minor point but it is actually quite significant. The number of acres burned often is applied as a measure of the success of a prescribed fire program. Describing the quality of fuels burned, however, is essential to truly gauge success. Burning fine fuels in a grassland, for example, is easier and cheaper for managers than clearing out ladder fuels in a dense thicket, but does little to safeguard a forest that is at risk of a severe fire.

Further, measures of sheer fuel mass, before or after fuels reduction, are not as important as where the fuels are and how a reduction in those fuels would affect resulting fire behavior. Consider for a moment a simple analogy: imagine a person concerned with weight loss saying, "Hey, I lost 9 pounds!" and hearing the reply, "But cutting off your arm doesn't help!" Yes, a reduction has occurred but it will not result in achieving the goal: improving health! Similarly, with fuels, eliminating all fuels in one area, rather than thinning the same mass of fuels over a larger area, and in a more heterogeneous pattern, would not achieve the goal of reducing the risk of severe fire (Stephens & Ruth, 2005).

By studying where fire is likely to occur on a landscape and targeting those locations, for example, a manager might decrease the risk of a severe fire more than by treating all areas lightly or a select area intensively. While actual fuel reductions in all three cases might be the same, the effect of the treatment on reducing potential fire behavior and effects is the best measure of success.

This approach requires a kind of risk assessment rather than a reporting of mere measurements. Risk assessment is the process of estimating the likelihood and magnitude of the occurrence of an unwanted adverse effect (Fairbrother & Turnley, 2005). Such an approach is more compatible with the complexities of fuels loads and fire hazards than reporting acres burned.

There are a variety of methods available to assess hazards. In some cases, vegetation or fuel condition-class systems are used to identify and prioritize areas in need of treatments, i.e., how many fire return intervals have been missed? It has been reported, however, that this is a poor measure that does not actually reflect the true hazards of fire. Missing 10 fire-return cycles in a xeric ponderosa forest, for example, many not be as risky as missing just several in a more mesic or hydric mixed conifer system (when it comes to fuels, productivity matters) (Stephens & Ruth, 2005).

Further, managers must target a certain kind of treatment to a specific kind of vegetation and fuel. Reducing forest cover may be a general goal, but in some systems, it may increase temperatures and wind speeds (Stephens & Ruth, 2005; van Wagtendonk, 1996). In other words, reducing crown fuels might have an undesired effect of exacerbating fire behavior. Another example is that mechanical fuels treatments can reduce surface, ladder, and crown fuels to reduce fire behavior. This reduction in fuels loads is not the best measure of success because the logging residues from this process may increase ground and surface fire intensity and severity (Franklin & Agee, 2003). Again, the best measure would be the resulting change in fire behavior.

FACING CONSTRAINTS: CAN FIRE BE RETURNED TO THE LANDSCAPE IN A CONTROLLED FASHION?

Wildland fire use policy recommends careful and gradual reintroduction of fire into landscapes to reduce fuels and potential wildfire behavior (Stephens

& Ruth, 2005). At the same time, the sociopolitical context around fire – both prescribed and wild – is increasingly complex (DellaSala et al., 2004). Institutional capacities to implement prescribed fire may be limited due to any of a combination of physical, socio-physical, budgetary, and resource constraints.

An apt lesson on the exigencies of reintroducing prescribed fire comes from Sequoia National Park in the late 1990s. The intentional reintroduction of fuel-reducing prescribed fires to the Mineral King Watershed was thwarted over three consecutive summers by a remarkable sequence and diversity of events. First, application of fire was prevented by the escape of other, lower-priority prescribed fires in the park and by the resulting diversion of fire-fighting resources and abundance of smoke. The next year, a federal fiscal crisis prevented the Park Service from spending money on fire projects during a key period in autumn. The third year, an exceptionally wet and heavy winter increased fine fuel loads and kept fuel moisture levels too high throughout the fire season to reintroduce fire (Menning, 2003).

When it comes to restoring a natural disturbance such as fire, the limiting factor may be physical, such as the very wet conditions in that third year in Sequoia National Park. In many cases, however, the constraint may not be physical at all; it may be social (such as the second summer) or some combination of a social constraint caused by physical conditions (the first summer). In other words, what is important is not what is *physically possible* but what is *feasible* given physical, climatic, social, institutional, and fiscal constraints.

Physical Factors Affecting Reintroduction of Fire: Weather, Terrain, and Fuel Loads

Weather, which cannot be controlled, is a frequent constraint on prescribed fire: severe, wet winters, or simply poor weather at the time of planned fire may result in no opportunity to burn. In areas without long, cold winters, the weather may simply be too hot, dry, or windy: conditions may rarely enter a safe "prescription" for allowing burns. Regionally, the occurrence of wildfire may be governed by unusual weather (Swetnam, 1993).

In Southern California, a debate has been waged over the last decade about the sources of differences between landscape vegetation patterns in the brush chaparral communities. Minnich has argued that differences in vegetation – and resulting fire patterns – were due to past landscape management (Minnich, 1998, 2001; Minnich & Chou, 1997). Several other authors, however, have been able to demonstrate that vegetation management is far less significant a factor in the occurrence, extent, and repetition of fire than are weather conditions (Keeley & Fotheringham, 2001a, 2001b; Moritz, 2003; Moritz, Marco, Summerell, Carlson, & Doyle, 2003). Even Minnich agrees there are significant differences in fire weather on both sides of the U.S.–Mexico border (Minnich, 2001). In short, weather is the dominant factor in the pattern and extent of fire in these chaparral landscapes. Santa Ana winds, which occur primarily north of the border, often lead to large fires with rapid fire spread (Keeley & Fotheringham, 2001; Moritz, 2003).

Terrain may also be a major factor affecting the reintroduction of fire. Managers are often limited in efforts to influence fire behavior by the interaction of terrain with the weather that passes over it (DellaSala et al., 2004). Extreme slopes limit access and increase the danger to fire fighters in upland positions.

Extreme conditions – simply too much fuel – commonly constrain the application of prescribed fire. Heavy initial fuel loads increase risks and liabilities of prescribed fire spreading beyond containment (Yoder, 2004). A dense understory may provide too much laddering that would carry fire into the forest canopy (Agee, 2003, 2004; Menning & Stephens, in press; Stephens & Ruth, 2005). High fuel loads combined with volatile weather may preclude the use of fire through an entire fire season.

Social and Institutional Roadblocks

Even when physical factors do not constrain fuel treatments such as prescribed fire, social factors may prevent its implementation. These may take a variety of forms such as concern over perceived risks, intolerance of physical conditions (smoke or aesthetics), limited agency budgets, agency resource allocations and priorities that emphasize other goals, and a lack of broad social acceptance. Resource managers may put considerable effort into understanding the physical potential of an action and economic efficiency, but may devote too little effort into understanding their project's social acceptability (Shindler et al., 2002). Science and economics inform decision-making, but actions play out in a social context and that is often inadequately considered (Stephens & Ruth, 2005).

Community Buy-In and Associated Risks

Communities are naturally concerned with the wildlands around them; in the era of expansion into the wildland–urban interface that interest is heightened.

Unfortunately, an absence of public understanding and participation makes it difficult or impossible to implement a plan (Shindler et al., 2002). identify 10 problems that often occur in decision-making about public lands with regard to the communities they affect. These impediments to considering social context include: a lack of public trust in land management agencies limits support; an agency focus on decisions rather than decision-making processes can result in less social support for actions; prescriptive one-size-fits-all approaches often ignore important local context, conditions and attitudes; rational or technical models do not adequately incorporate social concerns; different opinions about what is "natural" make it challenging to agree on "natural" condition goals; the public is often confused by how to deal with the variety of uncertainties and risks involved in plans; information does not always lead to understanding or agreement – although those presenting a plan may believe it will; and while members of the public do not always respond verbally, silence does not necessarily mean acceptance or approval (Shindler et al., 2002). Each of these problems demonstrates how difficult it may be to get the public's buy-in to a project, especially a volatile one involving the risks and uncertainties of fire (see Chapter 9 by Ganz et al. for a further discussion of the challenges to community buy-in with fire mitigation).

This reluctance of the public to trust or engage fully in a proposed management plan is exacerbated in the wildland–urban interface because the non-ecological impacts of fire include aesthetic values, economic losses, and damage to structures and the community (Hardy, 2005). In other words, the effects are directly felt by the public. Consequences are not abstract or distant.

Building trust may be especially difficult in the face of uncertainty, as there always is when trying to predict the future or determine the probabilities of different outcomes (O'Laughlin, 2005a, 2005b). The "Healthy Forests" initiative, for example, has struggled due to criticism that it is a thinly disguised logging program, not focused on real reductions of fuels hazards (O'Laughlin 2005a, 2005b).

Despite the difficulty of doing so, being candid about uncertainty is important; the public may want certainty but a false offer of certainty can lead to more damage than attempting to explain the complexity of the consequences of different approaches. Because hazards and risks cannot be eliminated, just altered or reduced, the public needs to understand the relative risks. The more the public understands about the relative hazards of different approaches – including non-action – the more acceptable the choices may become (O'Laughlin 2005a, 2005b).

Thinking about how to involve the public is changing gradually and being articulated in regional fire plans. Collaboration with non-governmental organizations, promoting community assistance, and increasing incentives for private landowners to create defensible space are some of the "core principles" espoused in the Western Governors' Association 10 year Comprehensive Strategy (WGA, 2001).

Physical Factors Interacting with the Social: Smoke Production

Smoke is a physical consequence of fire to which the public may react very strongly. In Sequoia National Park, for example, wildfires put so much smoke into the air that the local community became "smoke-saturated" (Menning, 2003). As a consequence of the resulting severe criticism from local residents, the Park Service had to cancel several planned prescribed fires; in the public's view, the park had exceeded its smoke quota. Thus, a physical factor may become a social constraint on the application of fire. As a result, the Western Governors Association recommended that all prescribed fires have smoke-management plans (WGA, 2001).

Budgets and Jurisdictions

Federal under-funding of fire mitigation has had serious and negative consequences. Basic budget shortfalls are common as the federal agencies systematically underestimate costs and, then, Congress underfunds these underestimates. As a result, actual suppression costs far exceed actual appropriations (GAO, 2002, 2004). This is exacerbated by the high costs of fighting fire in the wildland–urban interface due to complex protections, increased number of personnel allocated, and liabilities and risks (GAO, 2004).

Despite a dramatic increase in fire funding between 2000 and 2001 – from about $100 million to $400 million in one year – actual costs of fighting fire are considerably higher. In fact, suppression costs have exceeded the allocated budget every year between 1990 and 2004 (GAO, 2004). Many critics consider reform to the funding process to be essential to the success of fire suppression, prescribed fire, fire science, and fire management (GAO, 2004; Kline, 2004; Stephens & Ruth, 2005).

As a result of the under-funding of federal agencies' suppression efforts, these agencies must temporarily, and sometimes permanently, make up the shortfalls through their own budgets. Much of this is done via transfers from other agency funds. On average, the Forest Service transfers more than $500 million per year from other projects yet is only reimbursed by Congress for approximately 80% of that (GAO, 2004). As a result, the agency must shift approximately $100 million per year from other budgets (GAO, 2004).

The typical agency approach to these budget shortfalls is to transfer funds from programs that wouldn't spend the money until future years such as the Forest Service's Knutson–Vandenberg Fund, which is designated for forest restoration post-timber harvest. In the last few years, the agencies have been transferring from active programs, as well, because certain long-term programs were not being reimbursed and were becoming drained and their projects threatened (GAO, 2004).

In some cases, transfers even affect future *fire* operations: In 2002, the National Park Service removed $3.4 million from the budgets of 13 fire management facilities in 10 different parks (GAO, 2004). This could have a direct impact on the agency's ability to implement prescribed fire or fight wildfires the next year.

In addition, the allocation of fire funds primarily to suppression may perpetuate the tendency to react to severe fires rather than treat fuels to help minimize them. Seventy percent of the funding from the Federal Fire Plan is allocated toward suppression. That leaves too little for research and management. While there are many fire-fighting jobs funded, there are far, far fewer fire ecology and fuels-management positions (Stephens & Ruth, 2005). Ironically, funding these management and science positions might help reduce the need for more firefighters. As a result of spending so much on fighting fires, less is available for preventing fires with mechanical fuels treatments or prescribed fire (DellaSala et al., 2004; GAO, 2004). Allocating money and resources to prevent large, severe fires may be better spent than money spent on reacting to these fires when they do occur.

In addition to budgetary constraints, complex jurisdictional settings create confusion or inaction over who bears responsibility and who accrues benefits from fire suppression as well as fuels treatments (Yoder, 2004). In some cases, the agencies recognize the need to reintroduce fire – for ecosystem integrity and to reduce the likelihood of extreme fire behavior – but are often unwilling to accept the risks associated with allowing fires. The result has been a de facto continuance of the policy of suppression (DellaSala et al., 2004).

Fire-Fighting Resources

When it rains, it pours – or, in fire-speak, when it burns, a lot burns. Because fire is a process driven by weather, big fire seasons are often big throughout an entire region (Swetnam, 1993). As a result, agencies are often limited in their personnel and fire-fighting resources. If the people and equipment are allocated for wildfire suppression, there may be little opportunity to conduct prescribed burns that would reduce fuels loads and dampen possible wildfire severity.

Such limits on constraints may occur locally, as well. A prescribed fire program in a park or forest may be limited by escaped or large wildfires. The institution and the local public may be unable or unwilling to deal with more fire – even benign controlled fire – if they have dealt with too many recent wildfires.

Constraints from Fine Scale to Global

Ironically, efforts to conserve certain threatened or endangered species may sometimes harm them. A management action may be stopped because there is a short-term risk to a species. It is possible, however, that failing to act may result in a higher long-term risk (O'Laughlin, 2005a, 2005b). Single-species conservation programs often limit the ability to use prescribed fire but may increase the risk of severe wildfire that has much more dire consequences (Agee, 2003; Stephens & Ruth, 2005).

At the other end of the spectrum is the emerging issue of carbon dioxide emissions and their contribution to global warming. Local managers have been able largely to ignore the local implications of this issue until now, but there is mounting evidence that social and legislative constraints may soon begin to limit smoke and carbon emission from prescribed fires (Kline, 2004; Stephens, 2005).

WHEN AND WHERE SHOULD FIRE BE BROUGHT BACK TO THE LANDSCAPE IN THE FORM OF PRESCRIBED FIRE?

Reducing potential fire behavior and effects requires a range of solutions including mechanical treatment and controlled fire (Stephens & Ruth, 2005). In considering whether, where, and when to burn, managers need to assess and balance risks of actions and non-actions (Agee, 2003; O'Laughlin, 2005a, 2005b). Taking no action may be as risky as actively reintroducing a contagious event such as fire. Agee (2003) argues that not taking action *is* taking an action and there are consequences to it since fuel conditions have changed so much and fire will behave so differently than it would have historically. Certainly, passive management (natural fire) will not significantly reduce ladder and crown fuels without creating the very phenomenon sought to avoid: a crown fire. A whole-systems approach to fuels and fire risk assessment would balance the risks of bringing fire back into a system with the risks of not doing so.

The Failure of "One-Size-Fits-All" Solutions

One-size-fits-all approaches rarely work as not all forests are alike (Franklin & Agee, 2003; Hardy, 2005). Different forest types have different fire regimes and require site-specific approaches (DellaSala et al., 2004). Sometimes, even the same vegetation type in different geographic locations may require separate treatment approaches since the factors that affect fire, such as climate and topography, may fundamentally be different (Keeley & Fotheringham, 2001a, 2001b).

Individual vegetation and fuel types often have distinct characteristics that would prevent the broad application of simple and standardized approaches. Some forest types, such as lodgepole pine, require infrequent, high-intensity, high-severity fire for regeneration (Stephens, 2005; Stephens & Ruth, 2005) while others require very frequent, low-severity fire.

Vegetation types that historically had the most frequent fire may not be the most affected by long periods of suppression. As argued earlier, missing 10 fire-return cycles in a ponderosa forest, for example, many not be as risky as missing just several in a mixed conifer system (Franklin & Agee, 2003; Stephens & Ruth, 2005). In assessing such situations, the fuels productivity of a system is a more important factor than the number of missed intervals. Productive systems just yield more fuel and the resulting fires would be more – and uncharacteristically – severe (Agee, 2003; Stephens, 2005; Stephens & Ruth, 2005).

In some systems, weather conditions are far more critical to fire hazards than vegetation age or structure and fuel conditions. For example, fuels treatments in a Mediterranean system that has infrequent but severe fire events driven by "foern" winds – such as Southern California's Santa Anas – may have little effect on the reoccurrence of fire (Keeley & Fotheringham, 2001a, 2001b; Moritz, 2003). Instead, the key may be making every effort to stop ignitions during severe weather. Modifying fuels by mechanical or controlled fire is much less important. At the other end of the xeric–hydric spectrum, wetter coastal systems characterized by very infrequent, high-severity fire might not need any treatment at all. Any fuels reductions projects, whether mechanical or fire-based, could be more severe than wildfire itself (DellaSala et al., 2004).

Timing and species presence can be critical as well. Igniting prescribed fire at different times of the year than they occurred naturally may result in the local extinction of species adapted to the fire regime (Brown, Manders, Bands, Kruger, & Andrag, 1991). In contrast, when native species have been displaced, the new exotic species may have completely altered fire regimes within a system. Cheatgrass invasions, for example, typically shorten fire-return intervals and can drive native species extinct (DellaSala et al., 2004).

The "Process versus Structural Restoration" Debate

Many of the managers and scientists advocating forest restoration are divided into two camps. *Structural restorationists* believe we should alter forest structure to pre-Euroamerican conditions by silvicultural thinning followed by reintroducing fire (Agee, 2003; Bonnicksen & Stone, 1982; Covington et al., 1997; Menning, 2003; Menzel & Covington, 1995; Stephenson, 1999). They argue that the forest has become more homogeneous through ingrowth. Direct application of prescribed fire in unthinned stands could result in stand-replacing fires, thus missing the goal of reducing catastrophic fire risk.

If these suppressed forests are too homogeneous, they state, reintroduced fire would not result in a *diverse mosaic* of burn severity. In turn, this would lead to a subsequent landscape pattern of low contrast (homogeneous and even-aged) forest. They believe that these more homogeneous and ingrown forests may be more at risk to catastrophic fire. If ingrowth has increased canopy closure and built-up ladder fuels, it may be impossible to keep fire out of the crowns where it could spread quickly and devastatingly. Finally, they assert that the application of fire would not begin to recreate pre-Euroamerican forest conditions since forest structure and composition have changed from the pre-Euroamerican range of conditions.

In contrast, *process restorationists* would restore native disturbance types or processes, such as fire, directly, without modifying fuel loads mechanically. These advocates share with the structural restorationists the joint goals of recreating pre-Euroamerican forest structures and reducing risk (Baker, 1993; Menning, 2003; Stephenson, 1996, 1999; Vale, 1987). Process restorationists, however, maintain that one or two prescribed fires, carefully planned and managed, might begin to re-establish forest conditions with a low risk of catastrophic fire (Stephenson, 1996, 1999). This kind of iterative process restoration approach was in development at Sequoia National Park in the 1990's (Menning, 2003).

Process restoration, clearly, is not expected immediately to produce forest structure, pattern, and composition similar to that of pre-Euroamerican targets. First, many effects of fire on forest structure are not immediately apparent: mortality due to fire continues 8–10 years following the event (Reinhardt, Keane, & Brown, 2001; van Mantgem et al., 2003). Second, ground fuel levels often approach pre-fire mass 8–10 years after the fire when fire-killed vegetation falls and becomes horizontal fuels (Parsons, 1978). These fuels, which may be woodier and less continuous than earlier fuel loads, may be sufficient to carry wildfire through the forest to previously unburned patches. Hence, process restorationists generally recognize that the initial reintroduction of fire is just the first step in restoring forests. A second fire may be necessary to completely reduce fuel loads to within a normal range. Third, composition, structure, and pattern following a fire are all dependent on pre-fire conditions. If pre-Euroamerican forests, for example, had a large component of mature sugar pine (*Pinus lambertiana*) but these trees were absent from the modern forest, no fire would be able to bring them back into the current compositional and structural mix immediately. Fire might, however, establish the conditions in which these trees could return to the system over time.

Restoration Targets

It is tempting to say that restoration targets should mimic a range of historic conditions (Hardy, 2005). At the very least, the historic range of variability should be a benchmark for the possible states of an ecosystem (DellaSala et al., 2004). Agee (2003) suggests looking at historic patterns in an area to understand how fire occurred in it and how it has changed during suppression, and then identifying and targeting the areas with the highest fire hazard. Similarly, other authors state that forest and fuel conditions should be classified into different severity-risk levels (Franklin & Agee, 2003; Stephens & Ruth, 2005). Desired future conditions should not be based on historical forests in all cases. Conditions have changed too much and the condition of those forests might not be socially acceptable anymore (Franklin & Agee, 2003). Fire frequencies may be too high for public comfort and the resulting smoke production, for example, may be such a strong negative factor to local communities that support for prescribed fire programs would remain limited.

Physical Situations in Which Prescribed Fire Can Be Used Effectively

In areas that have been influenced by understory fire but now burn more intensely, fire can be brought back carefully as an effective tool in restoration of natural disturbance regimes (Brown, Agee, & Franklin, 2004; DellaSala et al., 2004; Kaufmann, 2004). As per Stephens and Ruth (2005), fuels treatment programs may be the most effective when targeted at specific locations to reduce extreme fire behavior, not just fuel loads.

First, priority for fuels-management should be in places where forests and communities intersect, the wildland–urban interface (Dombeck et al., 2004; GAO, 2002). Less emphasis should be given to remoter areas where large fires would have less impact on people, property, and infrastructure. Within the wildland–urban interface, the highest priority should be to target areas with high fuel loads and high probabilities of ignition (DellaSala et al., 2004).

Second, treatments and prescribed fire should be sited to minimize the probability of uncharacteristically severe fire spreading across the landscape (GAO, 2002; Stephens, 2005). Modifying fuels in these locations could have a significant effect on reducing the negative effects of future fire (GAO, 2002). Defensible fuel profile zones (DFPZs) (Stephens 2005; see Chapter 3 by Stephens and Collins in this volume for a further discussion of DFPZs) and strategically placed area treatments (SPLATs) represent broad scale efforts to reduce fire behavior and effects at the landscape (Finney, 2001; Stephens & Ruth, 2005).

Third, fire is the ideal tool in those landscapes where, from an ecological or philosophical perspective, ecosystem structure or function cannot be restored through mechanical means. These areas, such as National Parks, wilderness, and coastal chaparral are ready targets for prescribed fire (GAO, 2002).

Social Situations in Which Prescribed Fire Can Be Used Effectively

As articulated in earlier sections, an absence of public understanding and participation makes it difficult or impossible to implement a fuels or prescribed fire program (Shindler et al., 2002). As tempting as it is to say there is a magic bullet that will allow resource managers to "win over" the public when it comes to preventing fire with fire, there is not such a simple solution. The causes of public distrust and discord, and the often negative consequences of both severe fire and suppression of fire, make this a perpetually contentious issue.

In light of this, it seems necessary that in areas that need fuels treatments, a number of steps be taken. The first, broadly, would be to secure fuels treatment and fire-fighting funding (GAO, 2002, 2004). Ensuring that agencies have enough money available to fight fire would allow them to allocate money to the more important but easy-to-ignore approach of preventing fires through pre-treatment of fuels. Certainly, a lack of funding and reimbursements will continue to undermine the best laid plans. After all, no amount of quality planning can overcome inadequate funds to implement fuels treatments, including controlled fire plans.

Second, it seems absolutely essential that risk assessments of proposed actions and non-actions be presented together. Often, non-action is chosen due to any of a variety of constraints discussed in this chapter. If both managers and the public are forced to address the consequences of both treating and not treating fuels they might be more willing to make the necessary difficult choices. In the absence of such balanced risk assessments that consider short-term costs with long-term gains, it is easy to choose the path – often inaction – that is easiest in the short-term. It is important, however, to avoid thinking that simply providing better information will automatically result in the public's acceptance.

Toward this end, the third critical step is to earn the public's buy-in. To do this, managers will have to fully address the social constraints that confound the efforts of managers to implement fuels and prescribed fire programs. Shindler et al.'s (2002) work implies some positive steps that could be taken: build public trust in land management agencies with honesty and openness; focus on decision-making processes that build participation, understanding, and consensus rather than focusing on solutions alone; be considerate of important local context, conditions, and attitudes; beware of falling into the trap of assuming that all problems have technical solutions; recognize that technical models are poor at incorporating social concerns and work hard to ensure these concerns are factored in; and be forthright about the difficulty of defining desired condition goals.

At the end of the day, both the managers and the public will have to accept that there are no perfect solutions and that even the best plans with the lowest risk may involve discomfort or dissatisfaction. How much smoke now, for example, is acceptable, in order to prevent severe fires – and much more smoke later?

SUMMARY

There is broad agreement that western forests are in need of vegetation and fuel management and that one of the priorities should be the wildland–urban interface. While management is unlikely to change the absolute occurrence of fires it can influence their timing and intensity (DellaSala et al., 2004). As such, agencies should focus on reducing extreme fire behavior and effects rather than just reducing fuel loads. We should no longer rely on simpler measures of success such as acres treated or volume of fuels removed; the quality of the treatment – or non-treatment – is paramount. Risk assessment of fire behavior and effects of the proposed actions, *and inactions*, is important for providing the information needed to make these decisions (Fairbrother & Turnley, 2005).

In considering these fuels and fire plans we must always remember that context is critical. While a variety of physical, social, and economic factors constrain our ability to apply prescribed fire, we should proceed in those areas where it is physically possible and socially acceptable. This effort can be aided by increasing funding to fire prevention rather than just fire response, performing fire hazard risk assessments based both treatment and non-treatment options, and working to more honestly and fully engage the public. Such steps could help increase the range of social settings in which prescribed fire is a useful tool. The wildland–urban interface, in which fire, fuels, and the public collide, is likely to be a hotbed for this approach in the coming years.

REFERENCES

Agee, J. K. (1993). *Fire ecology of Pacific Northwest forests*. Covelo, CA: Island Press.

Agee, J. K. (2003). The fallacy of passive management. *Conservation Biology in Practice*, *1*, 18–25.

Agee, J. K. (2004). 2004 Starker lecture transcripts: The role of fire in forest restoration. Oregon State University.

Ansley, J. A., & Battles, J. J. (1998). Forest composition, structure, and change in an old-growth mixed conifer forest in the northern Sierra Nevada. *Journal of the Torrey Botanical Society*, *125*(4), 297–308.

Baker, W. L. (1993). Restoration of landscape structure altered by fire suppression. *Conservation Biology*, *8*, 763–769.

Biswell, H. H. (1989). *Prescribed burning in California wildlands vegetation management*. Berkeley, California: University of California Press.

Bond, W. J., & Archibald, S. (2003). Confronting complexity: Fire policy choices in South African savanna parks. *International Journal of Wildland Fire*, *12*, 381–389.

Bonnicksen, T. M., & Stone, E. C. (1982). Reconstruction of a presettlement giant sequoia-mixed conifer forest community using the aggregation approach. *Ecology*, *63*, 1134–1148.

Brown, P. J., Manders, P. T., Bands, D. P., Kruger, F. J., & Andrag, R. H. (1991). Prescribed burning as a conservation management practice a case history from the Cederberg Mountains Cape Province South Africa. *Biological Conservation*, *56*, 133–150.

Brown, R. T., Agee, J. K., & Franklin, J. F. (2004). Forest restoration and fire: Principles in the context of place. *Conservation Biology*, *18*, 903–912.

Caprio, A. C., & Swetnam, T. W. (1995). Historic fire regimes along an elevational gradient on the West slope of the Sierra Nevada, California. In: J. K. Brown, R. W. Mutch, C. W. Spoon, & R. H. Wakimoto (Eds), *Proceedings: Symposium on Fire in Wilderness and Park Management*, USDA Forest Service Report INT-GTR-320. Missoula, Montana, U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT (pp. 173–179).

Centers for Water and Wildland Resources (1996). Critical questions for the Sierra Nevada: Recommended research priorities and administration, Sierra Nevada Research Planning Team.

Covington, W. W., Fulé, P. Z., Moore, M. M., Hart, S. C., Kolb, T. E., Mast, J. N., Sackett, S. S., & Wagner, M. R. (1997). Restoring ecosystem health in ponderosa pine forests of the southwest. *Journal of Forestry*, *95*(4), 23–29.

Covington, W. W., & Moore, M. M. (1992). Restoration of presettlement tree densities and natural fire regimes in ponderosa pine ecosystems. *Bulletin of the Ecological Society of America*, *73*(2 Suppl.), 147–148.

DellaSala, D. A., Williams, J. E., Williams, C. D., & Franklin, J. F. (2004). Beyond smoke and mirrors: A synthesis of fire policy and science. *Conservation Biology*, *18*, 976–986.

Dombeck, M. P., Williams, J. E., & Wood, C. A. (2004). Wildfire policy and public lands: Integrating scientific understanding with social concerns across landscapes. *Conservation Biology*, *18*(4), 883–889.

Erman, D. (Ed). (1996). *Summary of the Sierra Nevada Ecosystem* Project Report (SNEP). Davis, California, Centers for Water and Wildland Resources.

Erman, D. C., & Jones, R. (1996). *Fire frequency analysis of Sierra Forests*. Sierra Nevada Ecosystem Project (SNEP). Final Report to Congress, v. II, Assessments and scientific basis for management options (pp. 1139–1154). Centers for Water and Wildland Resources, Report No. 37. Davis, CA: University of California, Davis.

Fairbrother, A., & Turnley, J.G. (2005). Predicting risks of uncharacteristic wildfires: Application of the risk assessment process. *Forest Ecology and Management*, 211 (1–2, Sp. Iss. SI), 28–35.

Finney, M. A. (2001). Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. *Forest Science*, *47*, 219–228.

Franklin, J. F., & Agee, J. K. (2003). Forging a science-based national forest fire policy. *Issues in Science and Technology*, *20*, 59–66.

Fried, J. S., Torn, M. S., & Mills, E. (2004). The impact of climate change on wildfire severity: A regional forecast for Northern California. *Climatic Change*, *64*, 169–191.

General Accounting Office (GAO). (2002). *Severe wildland fires: Leadership and accountability needed to reduce risks to communities and resources.* U.S. General Accounting Office: Washington, DC.

GAO. (2003). *Forest service fuels reduction.* U.S. General Accounting Office: Washington, DC.

GAO. (2004). *Wildfire suppression funding transfers cause project cancellations and delays, strained relationships, and management disruptions.* U.S. General Accounting Office: Washington, DC.

Greenlee, J. M., & Langenheim, J. H. (1990). Historic fire regimes and their relation to vegetation patterns in the Monterey Bay Area of California. *The American Midland Naturalist*, *124*, 239–253.

Hardy, C. C. (2005). Wildland fire hazard and risk: Problems, definitions, and context. *Forest Ecology and Management*, *211*(1–2), 73–82.

Johnson, K. N., Sessions, J., & Franklin, J. F. (1996). *Initial results from simulation of alternative forest management strategies for two national forests of the Sierra Nevada. Sierra Nevada Ecosystem Project*. Davis, CA: University of California Wildland Resources Center.

Kaufmann, J. B. (2004). Death rides the forest: Perceptions of fire, landuse, and ecological restoration of western forests. *Conservation Biology*, *18*, 878–882.

Keeley, J. E., & Fotheringham, C. J. (2001a). Historic fire regime in southern California shrublands. *Conservation Biology*, *15*, 1536–1548.

Keeley, J. E., & Fotheringham, C. J. (2001b). History and management of crown-fire ecosystems: A summary and response. *Conservation Biology*, *15*, 1561–1567.

Kline, J. D. (2004). *Issues in evaluating the costs and benefits of fuel treatments to reduce wildfire in the nation's forests.* U S Forest Service Pacific Northwest Research Station Research Note PNW-RN 542(October) 46 pp.

Leopold, A. S., Cain, S. A., Cottam, C. M., Gabrielson, J. N., & Kimball, T. L. (1963). Wildland management in the National Parks. *American Forests, 69,* 32–35, 61–63.

Martin, R. E., & Sapsis, D. B. (1991). Fires as agents of biodiversity: Pyrodiversity promotes biodiversity. In: R. R. Harris & D. C. Erman (Technical Coordinators). *Proceedings of the Symposium on Biodiversity of Northwestern California* (pp. 150–157). Report 29, Wildland Resources Center, University of California, Berkeley.

McKelvey, K. S., & Buse, K. K. (1996). *Twentieth-century fire patterns on forest service lands* (No. 41). Final Report to Congress, v. II, Assessments and scientific basis for management options (pp. 1119–1138). Centers for Water and Wildland Resources, Report No. 37. Davis, CA: University of California.

McKelvey, K. S., & Johnston, J. D. (1992). *Historical perspectives on forests of the Sierra Nevada and the Transverse Ranges of Southern California: Forest conditions at the turn of the century*. USDA Forest Service General Technical Report PSW-GTR-133. (pp. 225–246).

McKelvey, K. S., Skinner, C. S., Chang, C.R., Erman, D. C., Husari, S. J., Parsons, D. J., van Wagtendonk, J. W., & Weatherspoon, C. P. (1996). *An overview of fire in the Sierra Nevada.* Final Report to Congress, v. II, Assessments and scientific basis for management options (pp. 1033–1040). Centers for Water and Wildland Resources, Report No. 37. Davis, CA: University of California.

Menning, K. M. (2003). *Forest heterogeneity: Methods and measurements from extensive field plots, fire modeling, and remote sensing of the mixed conifer forest of the Southern Sierra*

Nevada, USA. Ph.D. Dissertation, Wildland Resource Science, University of California, Berkeley.
Menning, K. M., & Stephens, S. L. (in press). Ladder fuel hazard assessment: A semi-qualitative, semi-quantitative approach. *Western Journal of Applied Forestry*.
Menzel, J.P., & Covington, W.W. (1995). Changes in forest structure since fire regime disruption in the Walnut Canon area, northern Arizona. *Bulletin of the Ecological Society of America*, 76 (2 Suppl, Part 2), 181.
Minnich, R. A. (1998). Landscapes, land-use and fire policy: Where do large fires come from? In: J. M. Moreno (Ed.), *Large forest fires* (pp. 133–158). Leiden, The Netherlands: Backhuys Publishers.
Minnich, R. A. (2001). An integrated model of two fire regimes. *Conservation Biology*, *15*, 1549–1553.
Minnich, R. A., & Chou, Y. H. (1997). Wildland fire patch dynamics in the chaparral of Southern California and Northern Baja California. *International Journal of Wildland Fire*, *7*, 221–248.
Moritz, M. A. (2003). Spatiotemporal analysis of controls on shrubland fire regimes: Age dependency and fire hazard. *Ecology*, *84*, 351–361.
Moritz, M. A. M., Marco, E., Summerell, L. A., Carlson, J. M., & Doyle, J. (2003). Wildfires, complexity, and highly optimized tolerance. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(50), 17912–17917.
NWCG (2001). *National Wildfire Coordinating Group: Review and update of the 1995 federal wildland fire management policy*. National Interagency Fire Center (NIFC): Boise, ID.
O'Laughlin, J. (2005a). Policies for risk assessment in federal land and resource management decisions. *Forest Ecology and Management*, *211*(1–2), 15–27.
O'Laughlin, J. (2005b). Policy issues relevant to risk assessments, balancing risks, and the national fire plan: Needs and opportunities. *Forest Ecology and Management*, *211*(1–2), 3–14.
Parsons, D. J. (1978). Fire and fuel accumulation in a giant sequoia forest. *Journal of Forestry*, *76*, 104–105.
Parsons, D. J. (1995). Restoring fire to the giant sequoia groves: What have we learned in 25 years. In: J. K. Brown, R. W. Mutch, C. W. Spoon & R. H. Wakimoto (Eds), *Proceedings of a Symposium on Fire in Wilderness and Park Management.* United States Department of Agriculture Forest Service General Technical Report INT-GTR-320.
Reinhardt, E. D., Keane, R. E., & Brown, J. K. (2001). Modeling fire effects. *International Journal of Wildland Fire*, *10*, 373–380.
Roy, D. G., & Vankat, J. L. (1999). Reversal of human-induced vegetation changes in Sequoia National Park, California. *Canadian Journal of Forest Research*, *29*, 399–412.
Savage, M. (1994). Anthropogenic and natural disturbance and patterns of mortality in a mixed conifer forest in California. *Canadian Journal of Forest Research*, *24*, 1149–1159.
Shindler, B. A., Brunson, M., & Stankey, G. H. (2002). *Social acceptability of forest conditions and management practices: A problem analysis.* U.S. Forest Service Pacific Northwest Research Station General Technical Report PNW-GTR 537 (pp. 1–68).
Skinner, C. S., & Chang, C. R. (1996). *Fire regimes, past and present.* Final Report to Congress, v. II, Assessments and scientific basis for management options (pp. 759–786). Centers for Water and Wildland Resources, Report No. 37. University of California, Davis, CA.
Sousa, W. P. (1984). The role of disturbance in natural communities. *Annual Review of Ecological Systematics*, *15*, 353–391.

Stephens, S. L. (2005). Forest fire causes and extent on United States Forest Service lands. *International Journal of Wildland Fire*, *14*, 213–222.

Stephens, S. L., & Ruth, L. W. (2005). Federal forest-fire policy in the United States. *Ecological Applications*, *15*, 532–542.

Stephenson, N. L. (1996). *Ecology and management of giant sequoia groves.* Final Report to Congress, v. II, Assessments and scientific basis for management options (pp. 1431–1467). Centers for Water and Wildland Resources, Report No. 37. University of California, Davis, CA.

Stephenson, N. L. (1999). Reference conditions for giant sequoia forest restoration: Structure, process, and precision. *Ecological Applications*, *9*, 1253–1265.

Stephenson, N. L., Parsons, D. J., & Swetnam, T. W. (1991). Restoring natural fire to the sequoia-mixed conifer forest: Should intense fire play a role? *Proceedings 17th Tall Timbers Fire Ecology Conference, High Intensity Fire in Wildlands: Management Challenge and Options*, Tall Timbers Research Station, Tallahassee, FL.

Swetnam, T. W. (1993). Fire history and climate change in giant sequoia groves. *Science*, *262*, 885–889.

Urban, D. L., O'Neill, R. V., & Shugart, H. H. (1987). Landscape ecology: A hierarchical perspective can help scientists understand spatial patterns. *BioScience*, *37*, 119–127.

U.S. Department of Agriculture and U.S. Department of Interior (USDA-USDI). (2000). *US Department of Agriculture, US Department of Interior: A report to the President in response to the wildfires of 2000*. www.fireplan.gov\president.cfm

Vale, T. R. (1987). Vegetation change and park purposes in the high elevations of Yosemite National Park, California. *Annals of the Association of American Geographers*, *77*, 1–18.

van Mantgem, P., Stephenson, N. L., Mutch, L. S., Johnson, V. G., Esperanza, A. E., & Parsons, D. J. (2003). Growth rate predicts mortality of Abies concolor in both burned and unburned stands. *Canadian Journal of Forest Research*, *33*, 1029–1038.

van Wagtendonk, J. W. (1996). *Use of a deterministic fire growth model to test fuel treatments.* Final Report to Congress, v. II, Assessments and scientific basis for management options (pp. 1155–1166). Centers for Water and Wildland Resources, Report No. 37. Davis, CA: University of California.

WGA (2001). Western Governors' Association: A collaborative approach for reducing wildland fire risk to communities and the environment: 10-year comprehensive strategy. W. G. Association.

Yoder, J. (2004). Playing with fire: Endogenous risk in resource management. *American Journal of Agricultural Economics*, *86*, 933–948.

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PART II:
THE ECONOMICS OF HAZARDS

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CHAPTER 6

THE EFFECTS OF WILDFIRE DISCLOSURE AND OCCURRENCE ON PROPERTY MARKETS IN CALIFORNIA☆

Austin Troy and Jeff Romm

ABSTRACT

This paper analyzes the effects on housing prices of fire hazard disclosure in real estate transactions. In 1998, California passed the Natural Hazard Disclosure Law (AB 1195), which requires sellers to fill out a form disclosing to potential buyers whether their residence is in a statutory flood, wildfire, or seismic zone. This study looks specifically at whether homes in designated wildfire hazard zones in California saw any drop in value following this law. We found that location in a statutory fire zone is actually associated with a 3% positive price premium both before and after AB 1195, probably due to the unmeasured amenity values associated with location in the urban–rural interface. However, the combination of proximity to recent fire perimeters and post-AB 1195 disclosure does have

☆This chapter is based on findings from Troy and Romm (2006), a larger research report on the effects of flood and wildfire hazard disclosure, conducted by the authors for the California Policy Research Center, which also provided funding for this study.

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a negative effect on selling price. After AB 1195, homes in statutory fire hazard zones that were within five kilometers of the perimeter of a major and recent fire sold on average for 5.1% (or $10,600) less than comparable homes that were in statutory fire zones but not near the perimeter of a recent fire, while no such differential exists prior to the law. This indicates that state-level fire-disclosure requirements prior to AB1195 (which were numerous, but vague, limited to fewer hazard zones, and poorly enforced) were inadequate. Therefore, while disclosure on its own does not appear to have influenced the real estate market in all statutory fire zones, it does negatively impact prices when in combination with proximity to a recent major fire.

INTRODUCTION

The greatest growth pressures in California today tend to be found in some of the most hazardous land. As cities become more crowded and more highways are built, affluent residents have increasingly moved towards the amenity rich suburbs, as urban economic theory predicts (Mieszkowski & Mills, 1993). However, some of the qualities that make these suburbs so desirable to urban escapees – views, hillside locations, vegetation, and other natural amenities, made possible through low-density zoning or conserved land – also make them hazardous. Particularly in southern California, many of the newest and fastest growing suburbs are located in and around fire-driven ecosystems, such as chaparral, scrub, mixed conifer forest, and savannah oak woodland communities. The classic strategy of suppressing all wildfires so as to protect these communities has actually made the situation worse by increasing the risk of catastrophic conflagration. Meanwhile, planning and coordination to address this issue is piecemeal.

Given this trend, the extent of wildfire damage in the state is not surprising: the 2003 Southern California wildfires, $2.5 billion in damage; the 1991 Oakland Hills Fire, $1.9 billion; the 1993 Southern California firestorms, $1 billion; the 1999 statewide firestorms, 1,376 structures destroyed. Insurance providers have raised premiums or stopped offering fire insurance altogether in many areas of California that have a recent history of wildfire (Irby, Beall, Barrette, & Frago, 1999). Urban ratepayers in the state subsidize rural and fringe ratepayers, who pay $1 in fire-insurance premiums for every $1.09 in costs incurred by the insurance provider (CDF, 1995; see also Chapter 8 by Troy in this volume). As damage from natural disasters increases, the financial burden of government disaster assistance and hazard mitigation increases at the state and federal levels.

California attempted to address these problems in 1998 by passing a law regulating natural hazard disclosure in property transactions (AB 1195).[1] This law requires sellers to complete a Natural Hazard Disclosure Statement disclosing whether the property in question is located in statutory wildfire-, flood-, and seismic-hazard zones. Theory predicts that such information should enhance the efficiency of market allocations of land and development in hazardous areas, making prices and insurance premiums better reflect the costs and risks associated with living in hazard zones. Better information about the presence of hazards is expected to reduce the price of hazard-zone properties relative to comparable non-hazard-zone properties by increasing buyers' knowledge of the risks and additional expenses associated with living in them. The decrease in value due to disclosure should consist of the capitalized value of the added expenses, such as insurance, flood- and fire-proofing costs, plus an "option price," or risk premium that compensates for the uncertainty of potential damages and injuries in excess of insurance coverage (Macdonald, Murdoch, & White, 1987). While one can calculate how much less the "rational" home buyer will be willing to pay for a property based on added expenses, the price effect of risk aversion is far more difficult to predict because of various biases in the way that consumers translate perceived risks into financial terms (Kask & Maani, 1992).

Numerous studies have found that location in a statutory flood hazard zone has negative effects on property price (Donnelly, 1989; Harrison, Smersh, & Schwartz, 2001; Macdonald et al., 1987; Shilling, Sirmans, & Benjamin, 1989; Troy & Romm, 2004).[2] However, very little research has addressed this question for fire hazard. Among the few studies that have looked at the impact of fire hazard conditions on property values is one by Kim and Wells (2005), which found that fuel reduction treatments in forests around Flagstaff, AZ increased property values by an average of $190 per 1,000 square meters. Another such study by Loomis (2004) found that nearby housing prices dropped by about 15% following a major wildfire. A willingness to pay study in Michigan by Fried, Winter, and Gilless (1999) found that most respondents were willing to pay considerable amounts for incremental reductions in fire risk surrounding their homes, even though they were already insured.

While these studies indicate that consumers recognize and place a negative value on fire risk, they do not directly answer the question of how disclosure of fire hazard zone status impacts property markets. If disclosure does reduce prices in hazard zones then it might redistribute settlement away from hazardous areas and reduce the cost of structural, emergency, and regulatory forms of protection. This, however, begs the question: is reliable market information an effective policy substitute for other public forms of response to the potential impacts of natural hazards on property owners and public expenditures? Experience with the implementation of AB 1195 offers important clues in answering this question.

This study examines the effects of disclosure under AB 1195 on property values in wildfire-hazard zones throughout California. Using hedonic analysis of property transactions we isolated sales price differentials in statutory flood and fire zones before and after AB 1195 to determine how disclosure has affected prices. We also explored whether income, ethnicity, or local experience with disasters affected these price differentials. It should be noted, however, that as hazard zone designation does not indicate the degree of objective risk presented by the hazard, but only its presence or absence relative to a defined threshold, this study is unable to quantify how housing markets respond to different levels of risk. Rather it focuses on whether designation under AB 1195 has had any effect on market behavior.

POLICY BACKGROUND

Since 1985, California state law has required a seller and his or her agent to disclose all "material facts" about the condition of a property.[3] The Seymour-Petris Act created a transfer disclosure statement (TDS) that focused mainly on structural factors, such as the condition of the plumbing and the roof. As for hazards, it only asked the seller or agent to disclose whether the property had undergone a natural event, such as flooding, not whether the property is located in a hazard zone, i.e., is subject to potential natural hazards. The "Other" blank on the transactional disclosure statement became by default the primary location where real estate agents disclosed natural hazards requiring written disclosure, since a specific form for disclosing multiple natural hazards was lacking prior to AB 1195. The extent to which real estate agents have been completing the form is difficult to ascertain. However, prior to AB 1195 it is likely that many REALTORS® were not aware of their obligation to disclose for some natural hazards (especially fire), a situation that was probably exacerbated by the lack of mention of natural hazards on the form.[4] Further, it was ambiguous as to whether real estate agents were legally liable for such disclosure.

Prior to AB 1195, several statutes required certain types of natural hazard disclosure (NHD). In addition to two seismic-hazard disclosure laws (the

Alquist-Priolo Special Studies Zones Bill and the Seismic Hazard Mapping Act[5]), AB 1812 (1989) required residential transfer disclosure if houses were located in State Responsibility Area (SRA) fire zones.[6] SRAs are fire hazard zones located where no local fire department exists, and where the California Department of Forestry (CDF) has responsibility for fire protection. The disclosure provision informed buyers that they must maintain 30 feet of vegetative clearance around their homes and install spark arresters. Prior to AB 1195, there was no required transfer disclosure form dedicated to hazards; instead all hazard disclosure laws called for real estate agents or sellers to disclose in the "Other" section of the TDS form.

Early disclosure laws were hobbled by confusion and non-compliance. NHD requirements supposedly were not well known among real estate agents because many of them were located in the Resources section of the California Code. Real estate advisors typically overlooked this code section because so little of it pertained to their industry.[7] Other disclosure requirements were located in other Code sections and this dispersion further exacerbated this neglect. Most agents and brokers likely did not know about these requirements. Where they did, there was little threat of enforcement and few incentives, such as transference of liability, to encourage disclosure.

AB 1195 emerged in this context of haphazard and poorly publicized disclosure. Legislators realized that for disclosure to affect markets, the law needed to be publicized, incentives and disincentives had to be included for sellers and the real estate industry, and the various NHD requirements had to be combined into a single requirement.

Passed in 1998, AB 1195 requires home sellers of properties within designated natural hazard zones to show prospective buyers a form known as a NHD statement prior to escrow, which informs buyers that the property is potentially subject to these hazards.[8] The hazard zones include:

- Areas of potential flooding in the event of dam failure, designated by the Office of Emergency Services
- Special flood-hazard areas, corresponding to the 100-year floodplain, designated by the Federal Emergency Management Agency (FEMA)
- Very high fire hazard severity zones (VHFHSZs), designated by the CDF in conjunction with local governments (problems in the designation of VHFHSZs are discussed further in Chapter 8 of this volume by Troy)
- Wildland fire areas, or SRAs, designated by the CDF
- Earthquake-fault zones, designated by the state geologist and
- Seismic-hazard zones, designated by the state geologist.

The NHD statement warns buyers that "these hazards may limit your ability to develop the real property, to obtain insurance, or to receive assistance after a disaster." The NHD form is available from numerous companies in a variety of languages, by request. Once a local agency makes available maps showing parcels affected by the hazard zones, the seller and his or her agent are responsible for disclosing that information. The law additionally requires that homeowners in both categories of fire hazard zones maintain defensible space (no flammable vegetation) within and around their property, in accordance with local fire regulations. These are critical inclusions. By informing potential buyers that living in a hazardous location requires actual expenses as well as abstract risks, the negative consequences of living there are made more concrete and tangible.

By consolidating prior state and federal hazard disclosure requirements into a single NHD form and adding requirements for several new hazard zones, AB 1195 effectively created a form that was both easy to use and understand and that real estate agents and sellers could not easily ignore. Further, it granted a three-day rescission period during which buyers have the right to terminate a property transfer after signing a contract if proper disclosure was not made. This provision gave sellers and their agents an incentive to disclose early in the process rather than at the last minute, as was commonly the case when disclosure occurred in the past. Finally, in contrast to previous hazard disclosure laws, AB 1195 clearly articulated where real estate agents were liable for disclosure and where they were not. It makes clear which hazards the agent is responsible for disclosing, and it allows transfer of liability to a third-party contractor conducting the hazard report. Given that the third-party report generally costs only $50 to $100 and frees the real estate agent from direct and indirect liability, this alone may be one of the main driving forces behind the success of this law. A mail survey we sent out (whose response rate of 18% was too low to consider statistically valid), suggests anecdotally that a large majority of the homebuyers who responded saw the NHD form and understood it. It appears, however, that many consumers are not aware of the three-day rescission clause. If this clause were better publicized, it is likely that disclosure would occur in a more timely fashion.

STUDY METHODS

Hedonic analysis was used to isolate the price effects of disclosure under AB 1195. This method econometrically disaggregates the observed price of a good into a schedule of implicit, or "shadow" prices for each contributing attribute using multiple regression (Griliches, 1971; Quigley & Kain, 1970; Rosen, 1974). Hedonic pricing is particularly appropriate for studying how amenities and disamenities are capitalized into housing values, because the value of a property is determined by many quantifiable attributes. By relating these to price, consumers' willingness to pay for marginal changes in these attributes can be derived. In the second stage of hedonic analysis, economic welfare measures can also be derived (Freeman, 2003), although this is not attempted here. In this study, sales price was regressed against a number of explanatory variables relating to the neighborhood, proximity to amenities and disamenities, and structural characteristics of each house, in addition to a variable for proximity to fire perimeters and dummy (binary) variables for fire zone location (hazard zone variable), and transaction before or after implementation of the law (temporal variable). By creating an interaction term (that is, multiplying two variables together) between the temporal and hazard zone variables, the coefficients on that term can be interpreted as the effect on price of post-AB 1195 statutory hazard zone location and, indirectly, disclosure.

The analysis of the price effects of fire hazard was part of a larger study looking at the effect of other hazard zone designations, including flood zones. As such, the sampling strategy was designed to get a representative range of areas containing fire zones, flood zones, and hazard-free areas. Hence, although the sampling approach described here refers to flood hazard zones, this research paper only addressed the results from the analysis of fire zones.

We used a two-tier cluster sample method (Lohr, 1999) to achieve a representative sample of housing transactions from across the state. In this method, a set of aggregation units (often geographical) is sampled first and then the individual observations to be regressed are sampled within the chosen aggregation units. This is often done when the population to be sampled is too large to practically attribute with the information needed for a stratified design or when some of those sampling attributes are only available at the level of the aggregation unit. In this case, the first tier units were zip codes from across the state and the second tier units (used as observations for regressions) were properties within those zip codes.

Zip codes were stratified by population density, median 1999 housing price, and percentage of land area occupied by statutory hazard zones (Table 1).[9] Zip codes with very low population densities were discarded because they were likely to lack sufficient transactions. One of every nine zip codes was sampled from each cell, yielding 63 sample zip codes. The method

Table 1. Tier 1 Sampling: Number of Zip Codes Stratified by Housing Price and Population Density Classes.

Hazard = Just Flood Population Density					
		60–1000	1000–5000	5000 +	
House Price 1999	< 150K	49	50	20	Total 239
	150–250K	13	28	24	
	250K +	4	22	29	

Hazard = Just Fire Population Density					
		60–1000	1000–5000	5000 +	
House Price 1999	< 150K	48	14	6	Total 303
	150–250K	55	32	17	
	250K +	49	63	19	

Hazard = Both Flood and Fire Population Density					
		60–1000	1000–5000	5000 +	
House Price 1999	< 150K	43	10	0	Total 120
	150–250K	16	15	1	
	250K +	15	20	0	

Hazard = No Flood and Fire Population Density					
		60–1000	1000–5000	5000 +	
House Price 1999	< 150K	35	22	80	Total 403
	150–250K	3	36	98	
	250K +	3	43	83	

ensured that there would be enough zip codes with significant amounts of land in hazard zones (even with this oversampling of hazardous zip codes, only roughly one in five properties was located in a statutory hazard zone) and that a variety of neighborhoods would be included, across the spectrum of housing values and population density.[10]

Once sample zip codes were chosen, data sets of individual transaction records were obtained for residential properties in those zip codes (sampling intensity depended on the size of the population of transactions) for the period starting 18 months before the implementation of the law in June of 1998, to 19 months after it.[11] These property "points" were assigned a geographic locations through the process of address geocoding, using Geographic Information Systems software. A variety of control variables were coded for each property point (Table 2).[12]

The control variables, chosen based on a review of the hedonic analysis literature, can be roughly broken down into three types: property characteristics (e.g., number of bedrooms, house age, square footage), locational characteristics (e.g., proximity to employment center, amenities), and neighborhood socioeconomic characteristics (e.g., income, school quality, educational level). Some variables that were expected to be significant based on previous studies, such as presence of pools and fireplaces, were found not to add any explanatory power to the model due to collinearity with other variables (i.e. they varied with relation to price in a similar manner with other model variables), and so were excluded.

The main effects variables of interest were location in SRA fire zones, and VHFHSZs.[13] No distinction was made between properties in SRA zones and VHFHSZs. GIS data on fire hazard zones were obtained from the CDF. A digital map of perimeters of recent wildfires from CDF was used to determine how the effects of disclosure are conditioned by a neighborhood's recent experience with hazards. The distance of each household point to the nearest fire of greater than 300 acres occurring in the last 10 years before the date of sale was coded using three-month lags so that a property would not be coded with a fire occurring after the time of transaction (BURN5K).

We began tier-two sampling after all variables were coded. Property records were stratified by zip code and by hazard (or non-hazard) zone.[14] A sampling algorithm was created to oversample strata with low populations and undersample strata with high populations. This served to increase the proportions of hazard-zone properties and properties in zip codes with relatively low numbers of observations. Each stratum was assigned a sampling weight, for use in weighted least-square estimation, equal to the inverse of the sampling rate.[15] The algorithm was designed so that the total

Table 2. Regression Variables.

Variable	Description
Hazard variables (all binary)	
FLOOD	1 = in the FEMA Class A Flood Zone; 0 = not in that zone
FIRE	1 = in a statutory fire hazard zone; 0 = not in that zone
AFTER	1 = transacted after June 1998; 0 = Jan 1997 to June 1998
FIRE:AFTER	1 = Homes in fire zone that transacted after AB 1195
BURN5K	1 = a fire of greater than 300 acres has burned within 5 km of the house in the last 10 years; 0 = the previous is not true
FIRE:BURN5K:AFTER	1 = a fire of greater than 300 acres has burned within 5 km of the house in the last 10 years and house transacted in designated fire hazard disclosure zone after implementation of AB 1195.
Other variables	
PRICE	Transacted selling price of property
PHISP	Projected 1997 percentage Hispanic population by tract
ASSDSTCT	Assessed value of structure, normalized by mean
BATH	Number of bathrooms
BED	Number of bedrooms
TOTALRMS	Total number of rooms
SIZE	Total structure square meters
LOT	Lot size, square meters
AVG. RANK	Ranking of district schools by statewide 1–10 standard
AGE	Projected 1997 median age by tract
PUNEMP	Projected 1997 percentage unemployment by tract
MHHINC	Projected 1997 median household income by tract, normalized by mean
CBDIND2	Logged Central Business District Index[a]
D2HIWAY	Distance (km) to nearest highway or major arterial road
SDI1	Supply-demand index: Number of transactions by zip code over the population by year
PRATIO	Ratio of median zip code price to median state price
PADJ	Price adjustment factor: Percentage change in median home price by quarter relative to first quarter price, at zip code level

Quadratic terms used for fire model: SIZE, LOT, BED, D2HIWAY
TOTAL SAMPLES: 24,538

[a]The Central Business District Index was derived by dividing up the business districts within commuting distance of the sample zip codes into A, B, and C districts, based on density of employment and amount of revenue produced by companies in those districts, with A districts representing the highest density relative to revenue. CBDIND2 = log(Ra/Da + Rb/Db + Rc/Dc), where Ra = revenue of nearest A district and Da = distance to the nearest A district, Rb = revenue of nearest B district, etc.

number of hazard-zone properties sampled could be set equal to a specified proportion of the total number of non-hazard-zone properties sampled. The tier-two fire sample, which was taken out of a larger population, included 5,779 fire zone records (76%) and 18,712 non-fire zone records (45%).[16]

Weighted least-squares regressions were run on the data using a semi-log functional form.[17] One property of this functional form is ease of interpretation; coefficients can be interpreted as percentage changes in the response due to a marginal increase in an attribute. Both weighted and unweighted least-squares regressions were run and results were found to be robust to inclusion or exclusion of weights. Only weighted results are given here.

We used two regression models. In Model 1, in addition to all the control variables, we included terms for location in the fire zone (FIRE), transaction after AB 1195 (AFTER) and an interaction term between the two representing fire disclosure (FIRE:AFTER). In Model 2, we additionally included a term for recent experience with fire (BURN5K) and an interaction term representing recent experience with nearby fire for homes transacting in statutory fire hazard zones following AB 1195 (FIRE:BURN5K:AFTER). Demographic and socioeconomic variables did not interact significantly with the fire disclosure term for the fire data set so no such interaction terms were included for the fire hazard models.[18] R-squared values for models ranged between 0.75 and 0.77 and all variables had expected sign and significance. Regression results are given in Table 3.

RESULTS

The results of Model 1 (Table 3) indicate a positive premium of 3% for fire zone location prior to AB 1195, which does not change after the law's implementation (FIRE:AFTER is not significant). These results suggest an unmeasured amenity that might account for the high levels of demand for housing in the urban–wildland fringe areas where fire hazards are found. Because a variable accounting for this amenity is not included in our analysis, the positive variance in price has been accounted for by the FIRE variable.

Model 2 results suggest that the combination of proximity to a recent fire and post-AB 1195 disclosure negatively affects housing prices. A house selling in a statutory fire hazard zone after the law's implementation that was also within 5 km of a major (greater than 300 acres) and recent (within the last 10 years) fire sold for 5.1% less than a comparable fire zone home selling after the law's implementation that was not within 5 km of a recent

Table 3. Regression Results.

Model 1			Model 2		
	Value	*t* value		Value	*t* value
(Intercept)	9.974054	299.3104**	(Intercept)	9.972686	299.1669**
FIRE	0.031661	3.8741**	BURN5K	−0.0000331	−0.0069
ASSDSTCT	0.240928	54.7865**	FIRE	0.030905	3.7266**
TOTALRMS	0.007996	4.6694**	ASSDSTCT	0.240983	54.7132**
BED	0.03268	9.3635**	TOTALRMS	0.008198	4.7816**
CBDIND2	0.006169	3.2931**	BEDROOMS	0.03271	9.3738**
SIZE	0.00199	33.6516**	CBDIND2	0.006754	3.5540**
LOT	0.057109	18.2931**	SIZE	0.001987	33.5941**
MHHINC	0.218491	24.3960**	LOT	0.056723	18.1580**
AVG. RANK	0.007355	9.4156**	MHHINC	0.223842	24.0132**
PRATIO	0.536056	66.3316**	AVG. RANK	0.007027	8.9346**
SDI1	−0.70785	−2.1301*	PRATIO	0.534305	66.0112**
AFTER	0.045208	8.9114**	SDI1	−0.83788	−2.5008*
AGE	0.011914	18.8705**	AFTER	0.045136	8.8984**
PADJ	0.259992	14.3895**	AGE	0.011824	18.5505**
PHISP	0.001582	6.8392**	PADJ	0.262618	14.5043**
PUNEMP	−0.01402	−16.9092**	PHISP	0.001562	6.7547**
D2HIWAY	0.01904	7.5171**	PUNEMP	−0.01389	−16.7343**
I (BED^2)	−0.00107	−15.4808**	D2HIWAY	0.018777	7.4049**
I (LOT^2)	−0.00049	−13.7369**	I (BEDROOMS^2)	−0.00107	−15.5168**
I (SIZE^2)	−0.0000003	−28.8531**	I (LOTSQMET^2)	−0.00049	−13.5997**
I (D2HIWAY^2)	−0.00287	−10.2281**	I (SQMET^2)	−3E−07	−28.8332**
FIRE:AFTER	0.019207	1.8494	I (D2HIWAY^2)	−0.00285	−10.1573**
			FIRE:AFTER	0.051203	3.7051**
			FIRE:BURN5K:AFTER	−0.05117	−3.4991**
R^2: 0.7736297			R^2: 0.7737552		
F-statistic: 3754.789			*F*-statistic: 3444.073		

*Significant at the 95% confidence level.
**Significant at the 99% confidence level.

fire.[19] When this effect is controlled for (FIRE:AFTER:BURN5K), the effect of wildfire zone disclosure (FIRE:AFTER) actually becomes positive and significant, but at the same magnitude as FIRE:AFTER:BURN5K. In other words, prices actually went up significantly for homes in statutory fire hazard zones after the law's implementation except in locations near a recent fire. Such a home sold for $10,600 less than a comparable home in a statutory fire zone in which no fire had recently occurred, keeping all else constant.

Although the fact that the wildfire zone disclosure term (FIRE:AFTER) had a positive coefficient might suggest at first glance that disclosure caused no decline in price, the negative price effect in fire-disclosure zones near a recent fire is an indication that disclosure is having an effect at least in certain areas. Prices in fire zones went up after AB 1195 not because of fire disclosure, but because of increases in demand for urban fringe properties not captured in the control variables[20] of the model (which was unintentionally proxied by the wildfire zone term). If that effect could have been controlled for, we likely would have seen a decrease in purchase price due to wildfire zone disclosure and the decline would likely have been greater in fire hazard zones near the site of a recent fire. Instead, we saw an increase everywhere in the fire zone after AB 1195, but our results indicate that the rate of appreciation was much less in areas near a recent fire perimeter where disclosure was occurring.

DISCUSSION

Our model fails to find a perceptible negative effect of fire hazard disclosure by itself on housing prices. On the contrary, location in fire zones appears to be associated with increased sales prices. This is probably because the urban–wildland fringe areas in which these statutory zones are found are among the most desirable places to live because of their proximity to exurban scenic amenities, their association with low-density residential zoning, and their distance from the problems associated with urban cores. Lacking a variable to adequately control for these "desirability" factors, our model detects that price goes up in these areas. Prices may actually have gone down directly in response to fire hazard disclosure but, if so, our model is unable to quantify this effect. However, our model does find that prices are reduced when fire disclosure occurs for a property near the site of a recent fire. That is, a home selling after implementation of AB 1195 in a statutory fire hazard zone that is also within 5 km of a recent major fire is worth less than a comparable home in a statutory fire hazard zone that was not near the site of a major fire. However, since all fire zone properties are worth more than comparable non-fire-zone properties on average, this actually means that the positive premium associated with fire zone location is less for those properties near a recent fire. This result suggests that in the case of fire hazard, it is that experience, in combination with disclosure that has the greatest effect on consumer behavior.

Fire insurance availability and pricing may help explain the results (see Chapter 7 by Miller and Chapter 8 by Troy in this volume for further discussion of insurance pricing). Before disclosure was mandated, many potential homebuyers in these areas may not have realized that their prospective home was in a wildfire zone and that they would either have difficulty getting adequate insurance coverage or would need to pay more for that coverage. While most homeowners have some homeowners insurance, according to the Insurance Information Network of California, many do not know how much coverage they have, and consequently have insufficient coverage.

After AB 1195 was implemented, homeowners were probably more aware that they lived in such a zone and potential buyers were probably more concerned about the availability and affordability of insurance. Disclosure served as a cue to homebuyers to do more research about the availability and pricing of insurance, especially when combined with the telltale signs of recent fire in the area. In areas where a recent fire had occurred, there was a good probability that insurance would have been either unavailable through the private markets, very expensive, or inadequate, any of which would have lowered the selling price. Better information about the difficulties or costs associated with adequately insuring a structure in such a zone should translate into lower bids. Another possibility is that following a major fire, nearby houses received "non-renewal" notices from their insurance companies, stating that they would no longer cover the property, after which many homeowners might have sold their properties, resulting in a reduction in property values throughout the neighborhood. In areas with required disclosure, that unavailability was likely harder to hide from prospective buyers than in non-designated areas. Therefore, the disclosure form may have encouraged prospective buyers to conduct more rigorous research on insurance availability. Regardless of the underlying mechanism, the results show that location near a recent fire by itself is not sufficient to reduce property values; rather, disclosure is also necessary.

Loss of coverage through private insurers does not necessarily mean that insurance is unavailable. Homeowners who cannot obtain coverage through the private market can do so through the State's FAIR (Fair Access to Insurance Requirements) Plan (discussed further in Chapter 8 by Troy in this volume), a state insurance pool of last resort. However, until June of 2001 (and hence for the time of this study) FAIR Plan insurance was available only in a few select areas in Southern California. Most of the fire hazard properties in this study were not located in these FAIR Plan zones, and so it is likely that many property owners in these areas were unable to get fire insurance or could only get it at extremely high rates.

Future research projects should pursue the questions raised in this discussion by obtaining maps of neighborhoods that insurance companies have ceased providing coverage for due to extreme fire hazard. If these proscribed areas saw the greatest statistical drop in property value, all else equal, this would be a strong indication of the role of insurance availability and pricing in guiding the market.

This research is unable to show that AB 1195 has affected property markets for all fire hazard zones, but it shows that it does so in some circumstances. If this result is correct and not a statistical artifact, it suggests that the law is not adequately internalizing risk in all residential areas subject to fire hazard. Even if this result is due to statistical bias and fire hazard designation does reduce values, the positive premium associated with the fire hazard zone variable suggests that the magnitude of reduction would be small as a percentage of home value. This contrasts with the results of our analysis of flood zone disclosure under the same law, which found a significant negative differential following mandated disclosure (Troy & Romm, 2004). Why might one hazard designation result in price reductions and not the other? First, flood designation comes with more significant statutory baggage. To qualify for most mortgages, a home must have a flood designation and, if found to be in a flood zone, the buyers must purchase federal flood insurance. This fact, and the pricing of insurance, is well known by many buyers and all agents and mortgage brokers, meaning it is generally reflected in the offer price. Fire hazard zone designation has no such financial trigger. Further, insurance comes generally from private companies, which do their own risk mapping quantifying degree of risk, unlike the VHFHSZ map, which is merely a binary designation and likely includes many areas that the industry considers only minimally hazardous. Hence, unlike with flood hazards, there is a lack of correspondence between the state designation and expected insurance costs. Second, neighborhoods with fire hazard zones are among the highest-demand real estate market segments in the state (e.g., Malibu, Pacific Palisades, Hollywood Hills). Given the value of homes in these neighborhoods, it would not be surprising if the magnitude of the price effect from fire hazard is so small relative to overall property values that it is drowned out by random statistical variance. Also, these neighborhood qualities may lead home buyers to display traits of bounded rationality and ignore salient features that, in the context of the home's qualities, seem unimportant at purchase. Third, as discussed above, the California FAIR Plan may actually be distorting the housing market by subsidizing the cost of living in a hazardous environment.

Mandatory hazard disclosure is still an important policy mechanism and will likely become more so as more homes are built in flammable environments. But, as this research makes clear, current disclosure policy is not sufficient to steer development from hazardous areas. While it could be improved through some fine-tuning, such as developing maps designating level of hazard, even a perfectly crafted disclosure statute is unlikely to be able to meet its policy goals because of less controllable factors, such as subsidized insurance and bounded consumer rationality. This underscores the need for coordinated planning for communities in the urban periphery. Given the fragmented nature of current fire safe planning, the state must take the lead in developing the necessary institutions for such planning.

NOTES

1. Originally CA Civil Code § 1102.6c, now Civil Code § 1103.
2. Some of the flood studies have found that the differential is equal to the net present value of the future stream of flood insurance payments, while others, notably MacDonald et al. (1987) have found that there is an additional risk premium, presumably for expected costs above and beyond those covered by insurance.
3. Civil Code 1102.6.
4. Interviews with Stan Wieg, California Association of REALTORS® (1999 and 2001).
5. The 1972 Alquist-Priolo Special Studies Zones Bill (Section 2621–30 of the Public Resources Code) called for transfer disclosure of a property's location in potential earthquake-fault rupture zones in certain "special study" areas along the San Andreas, Calaveras, Hayward, and San Jacinto faults. The Seismic Hazards Mapping Act of 1990 (sections 2690–2699 of Public Resources Code) called for disclosure in mapped areas of seismically induced ground-shaking, liquefaction, and landslide zones (more specific zones than the designation under the Alquist-Priolo bill).
6. Public Resources Code 4125.
7. Interview with Peter Detwiler (1999), staff director of the California Senate Local Government Committee and former staff director of the Senate Committee on Housing and Land Use.
8. Based on interviews with Peter Detwiler (1998 and 1999), and with Julie Snyder (1999), aide to state representative Hannah Beth Jackson, both of whom who were

involved in drafting the law. Information also came from Detwiler's 1998 article in *Real Estate Reporter*.

9. Three categories of population density and housing price were used. The zip codes were also stratified by four hazard categories: only flood zones present, only fire zones present, both present, and neither present. In this way, all categories were mutually exclusive. The "presence" of a hazard in a zip code was assigned based on whether the percent of hazardous land in the zip code exceeded a given threshold. For floods and urban fire zones, this threshold was 5%, and for wildland fire areas it was 25%. Because of the low number of hazard-zone properties relative to non-hazard-zone properties, zip codes belonging to the nine cells of the "no-hazard" group were dropped, leaving 27 cells in the matrix.

10. As mentioned earlier, this study of the effects of fire disclosure was part of a larger study looking at the effects of both flood and fire hazards on property markets in California. At the tier-one level, a single sample of zip codes was taken for the purposes of studying both floods and fires. Sampling design was intended to include a large number of zip codes including flood and fire zones, as well as non-hazard-zones, since the exact distribution of properties within these zones would not be known until the property data sets for those zip codes had been purchased. Tier-two sampling of properties points within designated zip codes occurred separately for the flood and fire studies, though. To obtain sample properties for the flood regressions, all 63 tier-one zip codes were sampled in tier-two sampling since flood-hazard zones are present in almost all zip codes. To obtain data for the fire regressions, only 40 zip codes were sampled – those with fire hazard zones. Therefore, tier-two sampling was done twice, with overlapping data, but in one case oversampling for properties in fire hazard zones and in one case oversampling for properties in flood-hazard zones.

11. Property transaction records were downloaded from Metroscan, an online property transaction database.

12. Demographic data were obtained from the 1990 Census and 1995 projections of those data, while market data came from various sources including the California Association REALTORS® and the Rand Corporation. Demographic data were at the tract level, while market data were at zip code and city levels.

13. Special flood-hazard area data came from the FEMA Q3, digital data set, and fire hazard zones were obtained as digital files from the CDF.

14. They were not stratified by transaction after the law because of the extreme complexity of adding a third stratification factor and because roughly 54% of transactions were from after the law and 46% from before.

15. The weighted least-squares method was used because of the non-proportional rate of sampling in tier-two sampling. These unequal sampling probabilities meant that certain strata were oversampled and others undersampled. When this is the case, individual observations from different strata yield different levels of "representativeness" and must be weighted accordingly. Weighted least-squares regression therefore weights up observations from strata with low sampling rates and vice versa (Lohr, 1999).

16. A separate draw yielding different numbers was done for the flood study.

17. The semi-log functional was determined to be appropriate through use of a Box–Cox transformation as well as through plotting of the residuals.

18. Fire hazard location (independent of AB 1195) did interact significantly with income; however, that term was not included in the models presented in this paper since it detracts from the main focus which is on the price effects of AB 1195.

19. However, all fire zone homes, even those near the site of a recent fire, sold for more, on average, than comparable non-fire-zone homes, even after AB 1195's implementation. What the results means is, those near the site of a recent fire are worth considerably (5%) less than they would have been had they not been near the site of a recent fire. After the law, fire zone homes near recent fires were only worth 3% more than comparable non-fire zone homes, while fire zone homes not near recent fires were worth 8% more.

20. This suggests that our price adjustment variable was inadequate to capture this trend.

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REFERENCES

California Department of Forestry and Fire Protection (CDF). (1995). *California fire plan*. State of California, Sacramento, CA.

Donnelly, W. (1989). Hedonic price analysis of the effect of a floodplain on property values. *Water Resources Bulletin*, *25*, 581–586.

Freeman, A. M., III. (2003). *The measurement of environmental and resource values: Theory and methods* (2nd ed.). Washington DC: Resources for the Future.

Fried, J., Winter, G., & Gilless, K. (1999). Assessing the benefits of reducing fire risk in the wildland-urban interface: A contingent valuation approach. *International Journal of Wildland Fire*, *9*, 9–20.

Griliches, Z. (1971). *Price indexes and quality change*. Cambridge, MA: Harvard University Press.

Harrison, D. M., Smersh, G. T., & Schwartz, A., Jr. (2001). Environmental determinants of housing prices: The impact of flood zone status. *Journal of Real Estate Research*, *21*, 3–20.

Irby, B., Beall, B., Barrette, B., & Frago, M. (1999). *Wildland fire hazard assessments: A volume of the I-Zone Series*. Berkeley, CA: University of California Forest Products Lab, FEMA, California Department of Forestry, California Office of Emergency Services.

Kask, S. B., & Maani, S. A. (1992). Uncertainty, information, and hedonic pricing. *Land Economics*, *68*, 170–184.

Kim, Y., & Wells, A. (2005). The impact of forest density on property values. *Journal of Forestry*, *103*, 146–151.

Lohr, S. L. (1999). *Sampling: Design and analysis*. Pacific Grove, CA: Duxbury Press.

Loomis, J. (2004). Do nearby forest fires cause a reduction in residential property values? *Journal of Forest Economics*, *10*, 149–157.

Macdonald, D., Murdoch, J., & White, H. (1987). Uncertain hazards, insurance, and consumer choice-evidence from housing markets. *Land Economics*, *63*, 361–371.

Mieszkowski, P., & Mills, E. (1993). The causes of metropolitan suburbanization. *Journal of Economic Perspectives*, *7*, 135–147.

Quigley, J. M., & Kain, J. F. (1970). Measuring the value of housing quality. *Journal of the American Statistical Society*, *65*, 532–548.

Rosen, S. (1974). Hedonic prices and implicit markets: Product differentiation in pure competition. *Journal of Political Economy*, *82*, 34–55.

Shilling, J. D., Sirmans, C. F., & Benjamin, J. D. (1989). Flood insurance, wealth redistribution, and urban property values. *Journal of Urban Economics*, *26*, 43–53.

Troy, A., & Romm, J. (2004). Assessing the price effects of flood hazard disclosure under the California natural hazard disclosure law (AB 1195). *Journal of Environmental Planning and Management*, *47*, 137–162.

Troy, A., & Romm, J. (2006). *An Assessment of the California Natural Hazard Disclosure Law*. Berkeley, CA: California Policy Research Center, pp. 62.

CHAPTER 7

WILDFIRE UNDERWRITING IN CALIFORNIA: AN INDUSTRY PERSPECTIVE

Candysse Miller

California is no stranger to disaster.

Earthquakes, floods, landslides, brushfires and civil unrest have all struck the Golden State with catastrophic financial consequences.

Though the western states of New Mexico, Colorado and Arizona have all seen major wildfires in recent years, it is in California where dramatic population growth and increased fuel loads caused by fire suppression policies and prolonged drought have converged to create the greatest amount of damage.

Since 1970, 12 of the nation's top 15 most destructive wildfires have occurred in California, costing insurers more than $4.8 billion.[1]

Nationally, catastrophic wildfire has made up only a small percentage of overall insured disaster losses as shown in Fig. 1. (For insurance purposes, a "catastrophe" is defined as an event causing more than $25 million in insured losses.) Over the 20-year period from 1983 to 2002, tornadoes made up 32.1% and hurricanes 28% of the nation's disaster losses, while wildfire accounted for 2.3% of catastrophe losses.[2]

Like earthquakes, catastrophic wildfires may be rare and seemingly random, but they have the potential to create overwhelming losses in just one event.

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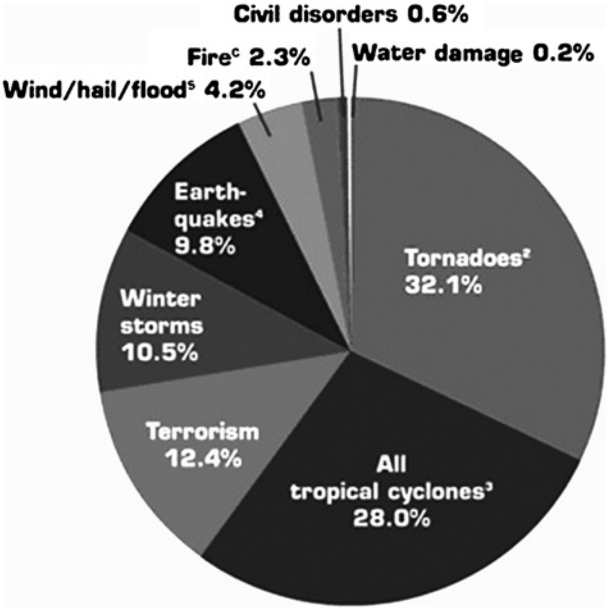

Fig. 1. Breakdown of Costs by Disaster Types.; (1)Catastrophes are all events causing direct insured losses to property of $25 million or more in 2002 dollars. Adjusted for inflation by ISO; (2)Excludes snow; (3)Includes hurricanes and tropical storms; (4)Includes other geologic events such as volcanic eruptions and other earth movement; (5)Does not include flood damage covered by the federally administered National Flood Insurance Program; (6)Includes wildland fires. *Source:* Insurance Services Office, Inc. (ISO); Insurance Information Institute (III).

The Oakland Hills fire of 1991 remains one of the costliest disasters – man-made or natural – in U.S. history. When its $1.7 billion in insured losses are adjusted for inflation, insurance payments for the Oakland Hills fire total more than $2.2 billion in present dollar rates. Estimated at $2.03 billion, the 2003 Southern California wildfires will cost insurers nearly half the $4.6 billion in homeowner insurance premium collected in the state in 2002.[3] Had the 1906 San Francisco earthquake and fire struck in 2002, it would have cost nearly $7 billion.[4]

But despite multiple fires causing billions of dollars in damage, how truly predictable are they? Though scientists know that natural disasters can strike certain areas – and are more likely to hit some regions more than others – is the science far enough along to be translated into detailed insurance underwriting?

The answer is mixed.

The business of underwriting homeowners insurance has undergone dramatic changes in the past decade, but to some degree, it is still largely the process that was in effect decades ago. Before receiving an insurance quote, homeowners are asked a handful of questions: How old is your home? How far is it located from the closest fire station? What type of roof does it have? Have you ever filed a homeowner insurance claim?

The price of an insurance policy reflects the costs of paying claims covered by that policy, as well as an insurance company's costs for such items as reinsurance. For example, if a community has a good fire department, the number of fires in that community will likely be few relative to comparable communities that lack a well-equipped or well-staffed fire department. As a result, fire insurance premiums in the better-prepared community will typically be lower than the other, less prepared community.

How does the insurance industry deal with the extraordinary costs incurred by catastrophes such as the 2003 Southern California wildfires or the 1991 Oakland Hills firestorm? Before Hurricane Andrew devastated the Florida coast in 1992, insurance companies accounted for hurricanes and other catastrophes with a special premium known as "catastrophe loading." Using catastrophe data spanning 30 to 40 years, and sometimes using data from several states subject to similar disasters, they developed the average regional cost for catastrophes.

However, since that time, more sophisticated computer modeling techniques have emerged that have helped make catastrophe underwriting more detailed and, ultimately, more accurate. Many insurers now base hurricane rates on meteorological data combined with their own exposure data. Similar models are being developed and marketed for brushfire risk analysis.

With each new fire, we learn of additional factors that may help in the calculation of risk. Is the home located on a slope? What is the road access to the community? Is it located in an area prone to high winds? What is the type and density of brush in the area? Do local building codes encourage replacement of shake-shingle roofs? What is the fire history of the area, and has local government taken steps through zoning and development standards to protect both existing development and future growth?

Other products assess the content and quality of building codes in a given community, with special emphasis on natural hazard mitigation.

The concept is simple: Municipalities with up-to-date and well-enforced codes should demonstrate better loss experience, and insurance rates can reflect that (see Chapter 3 by Paterson for a discussion of local fire safe zoning practices).

Based on a number of new underwriting products emerging on the market, homeowners insurance appears to be on the cusp of undergoing dramatic change that can provide a detailed assessment of an individual neighborhood or even a single home's claims risk.

Products now available utilize Geographic Information Systems (GIS) technologies to access county and city directories and hazard variables ranging from topography and wind speed to humidity and distance to heavy fuel loads (see Chapter 11 by Radke for a discussion of how GIS-based fire models are being applied). Such measures can provide strong indicators of potential fire losses, however, they also require follow-up assessment due to the possibility that measurables, particularly fuel loads, can vary over time.

Other systems evaluate building code effectiveness, from development to enforcement, with an emphasis on natural hazard mitigation. The goal in this case is to mitigate brushfire hazards with well-planned and maintained development.

Some insurance risk modelers claimed success rates of 90% and higher in identifying as "high risk" areas which ultimately burned in the 2003 firestorms.[5]

Nevertheless, as the California suburbs push into rural and foothill areas, the loss predictability of interface fires is still somewhat muddied. Firefighters had long predicted catastrophic fire in the San Bernardino National Forest. When it finally occurred in October 2003, fueled by heavy wind and severe tree die-off, it claimed hundreds of homes. Could the same be said in the rolling hills of suburban North San Diego County, where fires claimed about 2,400 homes that same week?

The California Fire Alliance has pinpointed 1,200 communities across the state that it considers at risk for wildfire. Likewise, research conducted by the California Department of Forestry has indicated that more than 60% of California's housing stock is at high risk of brushfire damage, including some 6 million in areas identified as "urban."[6]

In Laguna Beach, which lost 441 homes to wildfire in 1993, homeowners, local officials and insurers came to the table and asked themselves: "How do we make this better?" They found that even seemingly little actions could make a significant difference. They painted the curbs red to ensure safe passage for fire trucks on narrow streets. They made a commitment to rid the city of shake-shingle roofs. They improved the community's water supply. They even employed herds of goats to clear hillsides of flammable brush.

The seaside city, once at risk of losing competitive, open market insurance, is now not only a model for fire preparedness, but a thriving and competitive homeowners insurance market.[7]

The lesson – to homeowners, firefighters, local officials and the insurance industry – is the importance of encouraging mitigation. Firefighters' educational programs are a start. Smart land use planning that encourages fire resistant landscaping, defensible space and easy access for firefighting vehicles is another piece of the puzzle. Precise underwriting that provides a detailed analysis of wildfire risk – and prices accordingly – may be another.

The insurance industry is moving rapidly toward a form of underwriting that will gather detailed information about the homes it insures and the claims these homes create, ultimately creating a better understanding of risk that will allow insurers not only to identify potential future losses with greater accuracy, but also lead to a better base of information to create effective loss mitigation.

That being said, there are no certainties that new models will guarantee 100% accuracy in wildfire modeling. Unpredictable factors from gusty winds to blustery politicians can ultimately alter the course of accurate insurance underwriting.

In addition to a community's changing landscape, the changing interiors of homes can dramatically impact the accuracy of homeowners insurance underwriting. If policyholders fail to update their insurance contracts to include additions, renovation projects or large-scale acquisitions such as home media centers and high-end appliances, their insurance policies cannot be underwritten with complete accuracy.

NOTES

1. Insurance Information Institute (III).
2. Insurance Information Institute and the Insurance Services Office (ISO).
3. Insurance Information Network of California (IINC).
4. III.
5. ISO.
6. California Department of Forestry (CDF) and IINC.
7. Fire Safe Council of Laguna Beach.

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CHAPTER 8

A TALE OF TWO POLICIES: CALIFORNIA PROGRAMS THAT UNINTENTIONALLY PROMOTE DEVELOPMENT IN WILDLAND FIRE HAZARD ZONES☆

Austin Troy

ABSTRACT

This chapter discusses two California policies that unintentionally promote development in fire-prone areas. First is the state's Fair Access to Insurance Requirements (FAIR) Plan, a state-regulated statutory insurance industry association that provides basic insurance to property owners who are unable to obtain it in the private market. FAIR Plan was intended to be an insurer of last resort for rare cases when the private sector was unwilling to provide coverage. A functioning insurance market should discourage development in hazardous lands by charging appropriately priced premiums or denying coverage where hazards are extreme. The

☆This chapter is based on findings from Troy and Romm (2006), a larger research report on the effects of flood and wildfire hazard disclosure, conducted by the authors for the California Policy Research Center, which also provided funding for this study.

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FAIR Plan short circuits this mechanism and subsidizes development in highly hazardous environments by forcing insurers to provide coverage at a price that is far below what the market would charge. While FAIR Plan was envisioned to fill a need for a small number of homeowners who could not otherwise obtain insurance, instead enrollment in this program has skyrocketed. The second policy relates to how the state maps very high fire hazard severity zones (VHFHSZ), statutory zones designed for designating hazardous lands in urban and suburban jurisdictions with their own fire departments. Numerous legal loopholes have given communities wide leeway to keep land within their boundaries from being designated as VHFHSZ for disclosure and fire zoning purposes, even if those lands are objectively hazardous according to the state's criteria. Of most concern with these loopholes is the fact that California's natural hazard real estate transfer disclosure standard relies on these maps, meaning that home-buyers in communities that use these loopholes may be led into a false sense of security when purchasing a home because the statutory Natural Hazard Disclosure form presented prior to transfer asserts that no known wildfire hazard exists.

INTRODUCTION

Much of California's land area, particularly its areas of new urban development, is subject to wildfire hazards. While much of this area is mapped as hazardous land, as Chapter 6 by Troy and Romm in this volume suggests, mapping and disclosure are not enough to reduce consumers' willingness to pay to live in these areas. This indicates that the housing markets in the state are not adequately pricing and signaling risk, which has led to overdevelopment of hazardous lands.

The lack of a strong effect (except in mapped hazard areas near the site of a recent major fire) underscores the need for the state to enact policies that increase information about fire hazards and decrease incentives to overdevelop these areas. However, two state policies might actually be unintentionally providing an incentive for such development. The first is the state's fair access to insurance requirements (FAIR) Plan, a state-regulated statutory insurance industry association that provides basic insurance to property owners who are unable to obtain it in the private market, also known as an insurer of last resort.[1] The second is the state's very high fire hazard severity zone (VHFHSZ) mapping policy, a statutory designation for hazardous lands in urban and suburban jurisdictions with their own fire department. This chapter discusses how the former may serve to underprice risk and hence indirectly encourage development in fire prone areas and how the latter distorts information about risk in real estate transactions, which may lead homeowners into a false sense of security and, in the long term, increase development pressures on lands subject to natural hazards. It summarizes recommendations made by the author in a report published by the California Policy Research Center (Troy & Romm, 2006).

FAIR PLAN

In 1968, California created the FAIR Plan, which was designed to insure against risks of wildfire and riot, but soon came to cover other uninsurable risks. FAIR Plan policies provide insurance coverage to high-risk properties that otherwise cannot obtain coverage through the private market. This state-mandated association requires that insurers who do business in the state underwrite FAIR Plan policies in proportion to their market share in the state.

In 1996, State Insurance Commissioner Charles Quackenbush limited FAIR Plan brush-fire coverage to just a few designated zip codes in Los Angeles, Santa Barbara, Ventura, San Bernardino, and Orange Counties, given the increasing burden of brush-fire settlements on insurance companies. Said Quakenbush,

> The explosive growth of the FAIR Plan has profound implications for all insurance consumers…without action to curb this growth, some insurance companies would be unable to pay both their FAIR Plan assessments and the claims of their own policyholders in the event of a disaster such as an earthquake or brushfire, and that's unacceptable. Clearly, it was never the intent of the Legislature for the FAIR Plan to become one of the state's largest insurance companies.[2]

Much of the growth in FAIR Plan coverage in the nineties stemmed from the 1994 Northridge Earthquake, following which many private insurers pulled out of or reduced coverage in portions of the California market. The lack of earthquake coverage was subsequently taken care of by a new state insurance association, the California Earthquake Authority in 1999, but overextension of FAIR Plan brushfire coverage was clearly still enough of a concern to lead to its geographical curtailment. Initially existing policy holders were grandfathered in, but this changed in 2000, by which time roughly 36,000 FAIR Plan policies had been cancelled.[3] Because a number of these homeowners were unable to find any insurance coverage after being dropped, this put pressure on the California Insurance Commission under a new administration and new Commissioner, Harry Low, to remove the geographic restriction on FAIR Plan brushfire coverage provided that the homeowner proved that they approached three insurance companies and were denied. As FAIR Plan geographic restraints were eased, demand for FAIR Plan coverage grew, with over 180,000 homes insured through it as of 2002 (20,000 of those were in designated brush fire zones, but most of the remainder were in nondesignated zones which still have considerable fire risk),[4] and over 195,000 homes and $44 billion in exposure by 2004.[5] This demand was driven to a large extent by large insurers who had started dropping policyholders in high-risk wildfire areas following a string of severe firestorms in recent years, even if those areas had not recently burned.[6] Hence, as the number of fire-related losses grew, the FAIR Plan's role began to change from short-term insurer of last resort to a long-term insurer making up for large holes in coverage in the private market.

A bill proposed and never passed in the California Legislature (AB 2444, sponsored by Assemblyman Dutton in 2004) would have begun studying this problem in the market by requiring the FAIR Plan to provide an annual report to the Legislature stating the number of policies in force as well as the probable maximum losses in brush fire hazard zones. The impetus behind the bill was the belief, held by many, that the increase in the number of policies written through the FAIR Plan is an indication of problems in the state's insurance market and, by extension, development patterns. In a memo in support of AB 2444, the Personal Insurance Federation of California, which represents 45% of California's insurance, writes "in competitive, well-functioning markets, residual market mechanisms like the California FAIR Plan should have a relatively low number of policies as compared to the private market. The total number of policies in force and the probable maximum losses under the FAIR Plan can be an indicator of availability in the voluntary market and of the overall stability of the property insurance market."[7] Despite widespread support and no clear opposition the bill was never voted on.

An open question is whether the growth in FAIR Plan coverage has been driven more by the reduction in coverage by private firms or by the low cost of FAIR Plan premiums, which average $350.[8] While rates for FAIR Plans in California and other states were intended to be "break-even," according to *Insurance Issues Update*, they are generally lower than market rates for similar risk levels and have historically lost money.[9] However, FAIR Plan's low price is somewhat misleading because this "bare bones" policy only covers catastrophic loss due to fire and does not cover risks that are commonly covered by normal homeowners' policies, like theft, liability, and water damage caused by bursting pipes. Therefore, even though FAIR Plan premiums are generally about 50% less than market-rate premiums, a *Los Angeles Times* article quotes agent John Rodway of ARES Insurance Brokerage Service as saying that many FAIR Plan policyholders have to get supplemental Difference in Conditions (or "wraparound") policies and, between the two, end up paying 20–25% more in premiums than average single policy holders.[10] Nevertheless, even if this anecdotal observation is true, FAIR Plan ratepayers are still, in effect, being subsidized because they are paying less than they would have if the market actually insured those risks. For this reason, FAIR Plans have typically operated at a loss in the long term, and these losses are often passed on as higher rates for policyholders in the voluntary market.[11] The disconnect between FAIR Plan and market rates is illustrated by the fact that specialty insurers, such as Lloyd's of London, will write high-risk policies for expensive fire-prone properties when all other private insurers will not, but do so at rates many times higher than FAIR Plan. For instance, the *Riverside Press Enterprise* quotes a Corona, CA broker who said that in searching for coverage for a client's home abutting a National Forest, the only policy she could find, from Lloyd's, was $7,000 per year, almost four times what it used to be when insured through mainstream companies, and certainly much more than FAIR Plan's rates.[12]

If FAIR Plan is subsidizing insurance coverage in high fire hazard areas, then it distorts the pricing of risks and encourages continued development in hazardous wildfire zones by spreading the risks over the population of all insurance ratepayers. Removing the geographic constraints on the FAIR Plan increased the level of this subsidy, providing a perverse incentive to developers to build housing in some of the more hazardous and ecologically sensitive lands in the state, furthering the cycle of fire suppression and catastrophic conflagration.

This perverse incentive could be remedied – and in fact turned into a useful planning tool – by reinstating geographic constraints on the FAIR Plan for future development, while grandfathering in all existing structures. State and local planners would collaborate to designate a limited set of undeveloped brushfire hazard areas where FAIR Plan coverage would be permitted. This, combined with the restriction of FAIR Plan availability in other areas, could be used to direct and focus new development within geographically defined zones in which that risk could be better managed. By keeping the extent of these new communities contained, planners could design and more effectively enforce regulations to ensure better fire-safe design, materials, landscaping and emergency response.

VERY HIGH FIRE HAZARD SEVERITY ZONE MAPPING

Another state policy that may also be unintentionally encouraging development in hazardous places is statutory fire zone mapping. While the California Natural Hazard Disclosure Law (AB 1195), discussed in Chapter 6 of this volume, is a good step forward in conveying the importance of fire hazards in property transactions, currently many homebuyers receive imperfect or misleading information about those hazards because of inconsistencies in the designation of suburban fire zones. California's fire hazard zones are broken up into two types: State Responsibility Areas (SRAs), where suppression is the responsibility of the California Department of Forestry and Fire Protection (CDF), and VHFHSZs, which are designated zones that fall outside of areas where the state has the primary responsibility for fire prevention and suppression. In general this applies to jurisdictions that have their own professional fire departments, which includes the most heavily populated and developed parts of the state. Dwellings mapped as falling in either of these zones are subject to hazard disclosure in property transfer. Further, houses in both zones are required to maintain 100 feet of defensible space around them. This was recently increased from 30 feet with the passage of State Bill 1369 in late 2004.[13] SB 1369 also allows the state to place liens on houses in SRAs or VHFHSZs that do not comply with these requirements and requires homeowners in these zones who are proposing to build or construct additions to obtain certification from local officials that the proposed construction is in compliance with applicable local and state building standards, including those related to wildfire safety.[14]

Unlike the SRAs, which are consistently mapped across the state by the CDF, VHFHSZ mapping can be influenced by local governments. VHFHSZ designations were required under the 1992 Bates Bill (AB 337). However, the bill was not designed with disclosure in mind. It calls for CDF to identify VHFHSZs "in cooperation with" local agencies. Local governments could exempt land from designation as a VHFHSZ under the Bates Bill in several ways[15]: by declaring the "functional equivalence" of local fire-zoning regulations pre-dating December 31, 1992 to the state model ordinance; by rejecting the maps recommended by CDF; by redrawing the maps themselves; or by refusing to comply with the Bates Bill entirely. The state submitted the maps to the local government, which then had 120 days to either accept those maps or amend them; they could also redraw or eliminate them. CDF has neither the authority nor the resources to verify that a local government has functional equivalence in their ordinances, or that a local government's remapping was based on good science. Therefore, the local governments' claims always trumped the State's. California Government Code gives the local agencies the final word by stating, in section 51179.b, that "A local agency may, at its discretion, exclude from the requirements of Section 51182 an area identified as a very high fire hazard severity zone by the director within the jurisdiction of the local agency, following a finding supported by substantial evidence in the record that the requirements of Section 51182 are not necessary for effective fire protection within the area" and in Section 51179.d that "changes made by a local agency to the recommendations made by the director (of the California Department of Forestry) shall be final and shall not be rebuttable by the director." In other words, while lip service is given to having statewide mapping standards for areas with local fire departments, the state has no recourse to challenge a locality when it claims that it is exempt or equivalent. By exempting themselves from the state's mapping, these localities also become technically exempt from the defensible space requirements.

The question of where disclosure is needed for local responsibility areas has not yet been fully resolved. In the Civil Code section created by AB 1195, disclosure is required for VHFHSZs pursuant to either section 51178 (based on state designation) *or* section 51179 (based on local designation).[16] For many years the state had not resolved which took legal precedence, but due to the wording of the Civil Code section and to avoid potential liability to sellers and disclosure firms, the state recommends that properties in zones identified pursuant to either sections 51178 and 51179 should be subjected to disclosure.[17] According to the California Resource Agency's website, updated in 2003: "if a local agency with a VHFHSZ identified pursuant to Section 51178 has not designated the zone pursuant to Section 51179, disclosure would still be required, but the defensible space requirements of Section 51182 may not apply unless locally required pursuant to another code."[18] A more nebulous question, however, is whether the zones designated pursuant to Section 51178 (the supposedly more extensive state ones), really do include all the land that the state thinks is hazardous, or are reflective of local governments' exemptions or declarations of functional equivalence. In other words, the law is extremely vague as to what constitutes ultimate sources of data for these two standards.

Consulting the California Department of Forestry and Fire Protection's (CDF) Web site, it is evident that the VHFHSZs that are included on the state's official online GIS layer (update January 2006) only include a fraction of local responsibility jurisdiction land that CDF's nonstatutory wildfire hazard maps show as being highly hazardous. For instance, Fig. 1 shows

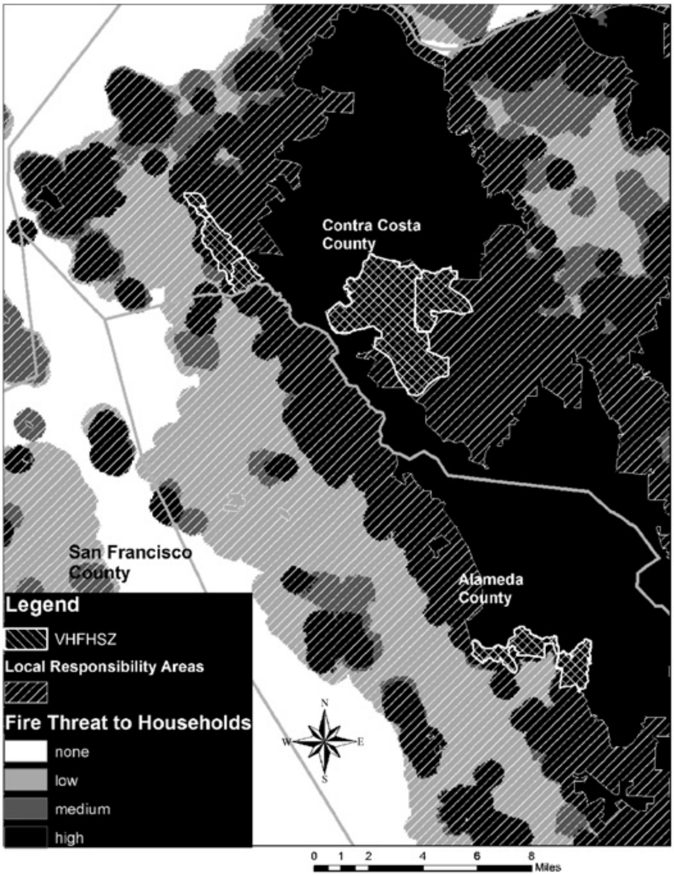

Fig. 1. CDF "Fire Threat to Households" Overlaid on Local Responsibility Areas and Very High Fire Hazard Severity Zones for the San Francisco East Bay.

the East Bay (Oakland/Berkeley), whose massive 1991 fire led to the Bates Bill in the first place. The land in black represents areas mapped by the California Department of Forestry's "Fire Threat to Households" layer as presenting the greatest threat of fire to humans, the single hatching represents Local Responsibility Areas (municipal jurisdictions where the locality is supposed to designate), and the double hatched polygons represent actual VHFHSZs as acknowledged in the state's official statutory designation map. This map clearly shows that the vast majority of hazardous areas in LRAs

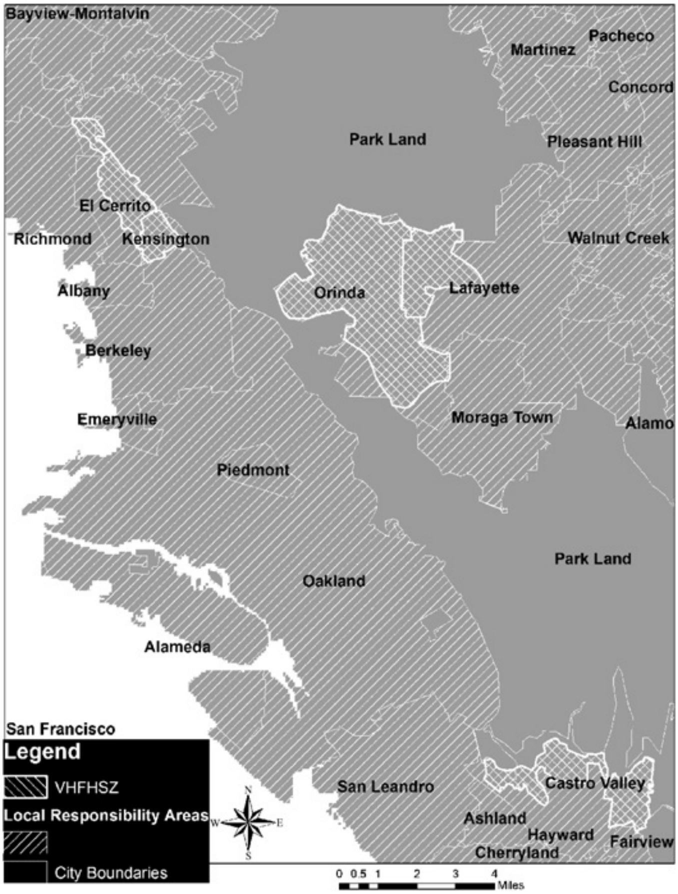

Fig. 2. Municipal Boundaries Overlaid with Local Responsibility Areas and VHFHSZs for the San Francisco East Bay.

are not mapped as such. Fig. 2 helps illustrate why this is. Only some local jurisdictions choose to designate – others do not. The fact that adjacent municipalities with similar fire hazards show up on the state map with different fire zone status suggests that those state maps clearly were influenced by local remapping and exemptions. In other words, through the confusing wording in the law relative to local ability to override state designations, it appears that the official state designations are really little different from the local ones.

The percentage of local governments failing to designate under the Bates Bill highlights the extent of the problem with fire zone mapping. As of 1999, of 209 jurisdictions with VHFHSZs mapped by CDF, only 99 did not challenge the designation (group 1). Fifty-two claimed that they "met or exceed" the Bates Bill minimums (group 2), and 58 "exempted" themselves (group 3), declining to participate either due to political reasons or local findings that the state mandate was not necessary for effective fire protection in their area (Irby, Beall, Barrette, & Frago, 1999). All jurisdictions were free to reject state VHFHSZ mapping and were under no obligation to provide their own mapping. Of the 52 in group 2, and the 58 in group 3, respectively ten and six adopted some kind of fire hazard zone – although in most cases not the state-designated VHFHSZ. All jurisdictions in groups 2 and 3 are technically exempt from any fire hazard disclosure requirements for a Local Responsibility Area, even though many of these jurisdictions contain extremely flammable landscapes. In other words, individual jurisdictions who figured out this loophole in time could simply opt out of designation with no consequences.

The end result of this problem is that many people who live in undesignated but still hazardous places within Local Responsibility Areas may be misled into a false sense of security when purchasing a home because the statutory Natural Hazard Disclosure form that is part of the transaction asserts that no known hazard exists.

There are several reasons why many communities containing flammable lands would be against having fire hazard zones designated within their borders. In a lengthy review of the fire regulations of all California communities containing designated VHFHSZs, the University of California Forest Products Lab and the California Department of Forestry found that most communities simply do not want the stigma of having a "high fire hazard" area within their borders, especially in areas that have significant and upscale residential development (Irby et al., 1999).

Such avoidance by local governments appears economically rational when analyzed in the context of the Tiebout framework of interjursidictional competition (Hamilton, 1975; Tiebout, 1956), which posits that residents "shop" for jurisdictions to live in based on distinct "service bundles" (e.g., school quality, environmental quality, other public services, etc.) and entry prices (housing price and property tax burdens), and that local governments compete for those residents who will maximize the tax base relative to service consumption – namely, wealthy people. To local governments, the imposition of onerous hazard-zoning regulations, including the negative designation in and of itself, could clearly be perceived as a way of reducing the attractiveness of the municipality's service bundle. Further, many municipalities on the urban fringe, eager for wealthy residents, are unlikely to want to publicize the fact that the scenic amenities that attract these residents in the first place are explicitly associated with natural hazards serious enough to warrant statutory disclosure.

Meanwhile, the incentives for municipalities to enact fire-safe planning are relatively low, as the costs of major fires are borne disproportionately by insurance companies, who pay losses to homeowners, and the state, which coordinates and funds suppression of major fires. From the homeowner's perspective, there is also little incentive to support such regulation. According to William Fischel (1985, 2001), because their largest single asset is generally their home, homeowners will often use the political process to help increase or at least maintain home values. Any regulatory burden that imposes costs or stigmas on real estate within a jurisdiction would, in theory, be fought by this constituency. This is likely to be particularly true for urban fringe communities where fire regulations could not only add homeowner costs that would be capitalized in home values, but also negatively affect the perception of the surrounding open space which, as numerous studies have found, is an important contributor to the value of properties (Acharya & Bennett, 2001; Geoghegan, 2002; Irwin, 2002; Nicholls & Crompton, 2005). The more powerful the affected homeowners are as an interest group in their jurisdiction, the more likely they will prevail in avoiding designation and the associated regulations.

The Oakland Hills fire of 1991 offers an example of the Tiebout process at work with wealthy homeowners. The Claremont Hills neighborhood constituted a large proportion of the wealthy housing of the city of Oakland. Following the fire, a large proportion of Oakland's wealthy residents found themselves without homes, but generally with large insurance settlements. In the context of the Tiebout model, these people's transaction costs for moving had been reduced significantly, and the city feared that it would lose those residents and their property-tax dollars to other nearby affluent jurisdictions (Topping, 1996). To encourage local residents to stay, the local government claimed "functional equivalence" to the Bates Bill, which exempted any of its lands from being mapped as VHFHSZs (although there are supposedly locally mapped hazard zones which do not appear on the state maps), and they rescinded previous local fire-zoning ordinances for the neighborhood, allowing residents to rebuild new houses with no setbacks and no design requirements. This example not only shows that homeowners do not like negative designations and land-use regulations, but that cities are responsive to wealthy constituencies. Where a potential loophole is offered to avoid designation, many cities will exploit that opportunity, with the result that local responsibility area fire maps used for disclosure purposes now greatly understate the extent of fire risk.

CONCLUSION

The use of disclosure and insurance to guide the real estate market in hazardous areas appeals to those who wish hazards mitigation to be driven more by personal responsibility than by government regulation; disclosure gives the individual economic actor better information and insurance prices risk. This study, however, shows that a pure market-based approach to managing exposure to natural hazards – where a buyer is assumed always both to be fully informed and to make economically rational choices – will likely not work in the current policy and economic landscape. Rather, markets are distorted by misleading or absent information, underpricing of risk, and government subsidies of infrastructure. For political reasons, it is unlikely that these problems will get fully fixed any time soon, but even if they did, it appears that when it comes to homeowners' location choices and how they assess risk, there will always be market failures, both because of an inability of consumers to act in a way that economists would call "rational" under risk and uncertainty (Kask & Maani, 1992) and because the government provides a safety net to all individuals, in the form of disaster assistance. This safety net serves a very important social purpose. But, because people rely on it when worst-case scenarios occur, a pure free-market approach to hazard mitigation based on self-responsibility is infeasible. The involvement of government in natural hazard mitigation and disaster assistance is inevitable.

Therefore, while disclosure and insurance are critical to improving the efficiency of land allocation, government regulation and planning are still needed to limit and direct development in hazard zones and ultimately to reduce the burden of disaster aid.

NOTES

1. Pursuant to Insurance Code section 10091(c).
2. As quoted by *City News Service*, May 22, 1996.
3. *Associated Press* State and Local Wire, June 6, 2001. "Insurance commissioner expands backup plan for high-risk areas", by Don Thompson.

4. *Los Angeles Times*, Sept 28, 2003: "Hard to insure; Homes from lush canyons to city cores are sometimes shunned by insurers. California's FAIR Plan can be a last resort," by Jeff Bertolucci.

5. *Insurance Issues Update, June 2006*: "Residual Markets," by Ruth Gastel, Insurance Information Institute (http://www.iii.org/media/hottopics/insurance/residual/).

6. *The Press Enterprise* (Riverside, CA), Oct 24, 2004. "From the Ashes: one year after blazes, lives are still affected," by Leslie Berkman.

7. Quoted from memo available at http://www.pifc.org/Media/pdfiles/2004/ppab2444.pdf.

8. *Kipplingers Personal Finance*, June 4, 2003, "High cost for skimpy coverage."

9. Gastel.

10. Bertolucci.

11. *Insurance Issues Update, June 2006*: "Residual Markets," by Ruth Gastel, Insurance Information Institute (http://www.iii.org/media/hottopics/insurance/residual/).

12. Berkman.

13. California State Government Code Sec. 51182 and Public Resources Code 4291.

14. This general requirement is laid out in Government Code Sec. 51189.a. Part b states that the specifics of these standards are to be determined by the State Fire Marshall's Office by January 2005. The State Fire Marshall has developed extensive and detailed draft standards which are sill pending approval, as part of their project entitled "Urban Wildland Interface Building Standards Development" (http://osfm.fire.ca.gov/UWIBS.html).

15. See http://ceres.ca.gov/planning/nhd/background2.html.

16. See http://ceres.ca.gov/planning/nhd/background2.html.

17. Interviews with Melissa Frago (1999, 2001).

18. http://ceres.ca.gov/planning/nhd/background2.html.

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REFERENCES

Acharya, G., & Bennett, L. L. (2001). Valuing open space and land-use patterns in urban watersheds. *Journal of Real Estate Finance and Economics*, *22*, 221–237.

Fischel, W. A. (1985). *The economics of zoning laws: A property rights approach to American land use controls*. Baltimore: John Hopkins University Press.

Fischel, W. A. (2001). *The homevoter hypothesis: How home values influence local government taxation, school finance, and land-use policies*. Cambridge, MA: Harvard University Press.

Geoghegan, J. (2002). The value of open spaces in residential land use. *Land Use Policy*, *19*, 91–98.

Hamilton, B. (1975). Zoning and property taxation in a system of local governments. *Urban Studies*, *12*, 205–211.

Irby, B., Beall, B., Barrette, B., & Frago, M. (1999). *Wildland fire hazard assessments: A volume of the I-zone series*. Berkeley, CA: University of California Forest Products Lab, FEMA, California Department of Forestry, California Office of Emergency Services.

Irwin, E. (2002). The effects of open space on residential property values. *Land Economics*, *78*, 465–480.

Kask, S. B., & Maani, S. A. (1992). Uncertainty, information, and hedonic pricing. *Land Economics*, *68*, 170–184.

Nicholls, S., & Crompton, J. (2005). The impact of greenways on property values: Evidence from Austin, Texas. *Journal of Leisure Research*, *37*, 321–341.

Tiebout, C. (1956). A pure theory of local expenditures. *Journal of Political Economy*, *64*, 416–424.

Topping, K. (1996). Planning for post-disasters. In: R. Slaughter (Ed.), *The I-zone: Urban–wildland fire prevention and mitigation* (pp. 66–96). Sacramento: California Department of Forestry.

Troy, A., & Romm, J. (2006). *An assessment of the California natural hazard disclosure law*. Berkeley, CA: California Policy Research Center, University of California Office of the President.

PART III:
COMMUNITY INVOLVEMENT

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CHAPTER 9

COMMUNITY INVOLVEMENT IN WILDFIRE HAZARD MITIGATION AND MANAGEMENT: COMMUNITY BASED FIRE MANAGEMENT, FIRE SAFE COUNCILS AND COMMUNITY WILDFIRE PROTECTION PLANS

David Ganz, Austin Troy and David Saah

Fire is a disturbance that plays a major role in forest ecosystems throughout the world. The participation of local communities in fire management and mitigation has been identified as a critical component to reducing the number and intensity of wildfires (Jurvelius, 2004). However, local communities confronting fire hazards are often complacent about fire management for a number of reasons, ranging from exclusion from the decision making process to a lack of incentives.

This chapter provides an introduction into the field of community involvement in forest fire planning and management. We start by defining the community-based fire management (CBFiM) paradigm and its numerous variants followed by a general discussion of the current status of CBFiM in

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the United States and abroad. In the following section, we detail the California Fire Safe Council as a prime example of CBFiM, which has been implemented across a range of contexts, from resource-dependent communities to suburban communities in the urban–wildland interface zone. Next we define the concept of "community" within the context of fire management and planning, pointing out some of the common and mistaken assumptions that are often made by outsiders about what constitutes a community. We further discuss some of the indicators for considering a process to be truly "community-based." We then discuss some of the critical ingredients to successful community involvement, building on case studies from around the world. Among these ingredients are community participants' sense of legitimacy of and ownership in the planning process, presence of meaningful incentives for planning and management, good communication, outreach, and information dissemination, and representation of the diverse interests in communities. The remainder of the chapter deals with institutionalization of the CBFiM paradigm, starting with a section on Community Wildfire Protection Plans (CWPP). These plans, which are required in many western US communities under the 2003 Healthy Forests Restoration Act (HFRA), illustrate many of the challenges and opportunities associated with institutionalizing CBFiM. Based on the lessons of the CWPPs, we then outline some of the challenges to institutionalizing a community-based approach. The chapter concludes by discussing the current state of the knowledge of CBFiM and suggesting areas for future research. While this chapter builds on the scholarly literature, it focuses more on current practices, programs, and institutions. A more detailed review of the scholarly literature on the subject of community involvement in fire planning is given in Chapter 10 of this volume, by Patricia Stokowski.

DEFINING COMMUNITY-BASED FIRE MANAGEMENT

Community-based fire management (CBFiM) integrates community action with the standard elements of fire management and mitigation, such as prescribed fire (managed beneficial fires for reducing hazardous fuel loads, controlling weeds, preparing land for cultivation, reducing the impact of pests and diseases, etc.), mechanical fuel treatment, defensible space planning, wildfire awareness and prevention, preparedness planning, and suppression of wildfires. In developed examples of CBFiM, communities are empowered to have effective input into land and fire management and problem solving and to self regulate to respond to fire and other emergencies. Its premise is that local people usually have most at stake in the event of a harmful fire, so they should clearly be involved in mitigating these unwanted events.

Prevention is one of the most important activities of CBFiM. This includes planning and supervision of activities, joint action for mitigation measures, fire monitoring and response, application of sanctions, and providing support to individuals to enhance their fire management tasks. Communities can be an important, perhaps pivotal, component in large-scale fire suppression, but should not be expected to shoulder the entire burden or coordinate the response at a broader level, since doing so requires considerable economies of scale that small communities do not possess.

While it is often associated with forests and forest management, CBFiM is not limited to working forests or rural landscapes but may extend to grasslands, scrublands, and, most importantly, the wildland–urban interface. CBFiM is thus applied to any land-fire scenario in which people have assets at risk.

Fig. 1 outlines a range of participatory approaches for fire management, including CBFiM. It shows that some modes of management allow for community input but do allow for meaningful community participation in the decision making process. Such an arrangement is not considered CBFiM as defined here. While it is important whether the program is initiated

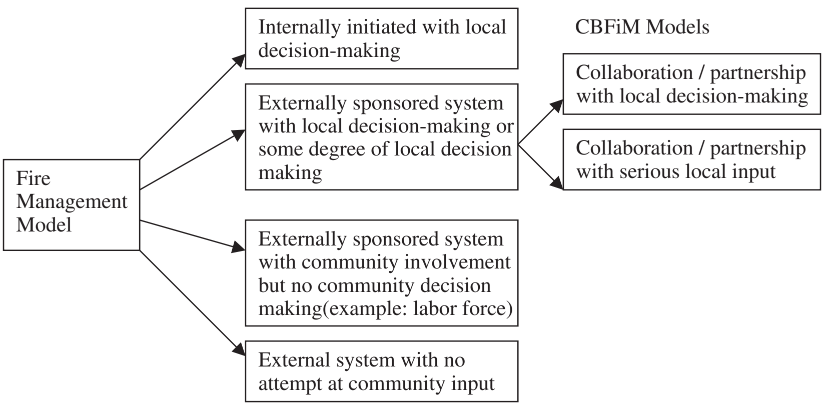

Fig. 1. Various Modes of Community Input in Decision Making in Fire Management. *Source:* Adapted from Ganz et al. (2003).

internally or externally, the initiation is not as important as the amount of credibility given to local decision making.

THE STATUS OF CBFiM TODAY

The idea of community protection from wildfire is not new. CBFiM is increasingly considered an integral component of participatory community development strategies and forest management. In particular, practitioners of community-based forest management (CBFM, as opposed to CBFiM) have recognized the integral contribution that CBFiM has to offer to participatory forest management. CBFiM is manifest today around the world, from the Fire Safe Councils in California (described in the next section), to formally recognized community forestry and fire management groups in the national parks of the Gambia, to collaborative fire protection networks in Southeast Asia working independently of governments.[1] These cases provided interesting similarities in their use of multi-stakeholder forums to discuss fire management systems despite their dynamically different contexts.

To varying degrees, governments around the world have begun to adopt collaborative CBFiM strategies. For example, in 2002 in the United States, the Healthy Forest Initiative (HFI) included fire management as a component of a broader strategy to improve the health of the United States' forests and rangelands. The Healthy Forest Restoration Act (2003) codified many of the goals of HFI in a statute, particularly expedited fuels reduction and community safety, and encouraged the use of CWPPs (Section 103(d)(2)), described later in this chapter. In the Philippines the government and its Department of Environment and Natural Resources (DENR) demonstrated their willingness to revise forest policies to address community needs and long term resource sustainability (Igsoc, 1999), in the process learning that when local people possess secure land and resource tenure, they strive to maintain the productive capacity of their land, in part through managing fire (Igsoc, 1999; Castillo, 2001). Within the Community-Controlled State Forests (CCSFs) of the Gambia, local people legitimately manage forests in traditional ways through the establishment of use zones on the periphery of government-owned forests. In these areas, local users are beneficiaries of revenue-generating agreements or recipients of accelerated investments into areas that are directly adjacent to forests. The CCSFs demonstrate the Gambia's shift from centralized and state-driven forest fire management towards decentralized and community-based management regimes. In Thailand, the Royal Forest Department worked together with 45 villages in

Nan province to form a Village Watershed Network to help coordinate village fire control responsibility and enable villages to better regulate the burning of forests for agriculture and hunting (Hoare, 2004).

In some cases communities coordinate the management of fire on their own with little help from government. In another example from Thailand (Fig. 2), a local community has taken action to protect forest resources in a remote location where the government has little capacity to help (Makarabhirom, Ganz, & Onprom, 2002).

Box 1: Case from Thailand:
Villagers from the Mae Khan watershed had been using fire in a traditional cultivation system. In the early 1990s, fire started to become a problem, spreading from one village to another and threatening valuable forested catchment areas. Communities came together to form a collaborative fire protection network around their forested areas. Today the villages have a coordinated system to protect the Mae Khan watershed.

All photographs by David Ganz

Fig. 2. Case from Thailand.

These are all limited forms of community involvement. They do, however, at least acknowledge the importance of local community organization in protecting and sustainably managing fire in and around settlements. More importantly, these examples from around the world illustrate how local communities can become increasingly involved in developing a collaborative, ecologically coherent, and sustainable model.

CBFiM IN ACTION: CALIFORNIA'S FIRE SAFE COUNCIL AND FIRE SAFE COUNCIL CLEARINGHOUSE

One of the foremost examples of CBFiM in action is the Fire Safe Council (FSC) of California (http://www.firesafecouncil.org) which works through grass roots local councils to educate, motivate, and empower citizens and residents to make their homes, neighborhoods, and communities safer from wildfire. The California Fire Safe Council began in 1993 by uniting organizations with diverse viewpoints to address a common threat – wildfire. The Council first focused on public–private partnerships with government and business. It has since evolved to assist communities to form local councils united by the common interests of fire prevention and loss reduction.

In the early development of the FSCs, the focus was on involving companies, associations, agencies, etc. to assist in fulfilling the California Department of Forestry's (CDF) public education goals through mutually beneficial partnerships. In the late 1990s, the CDF Administrative Units realized in the process of developing the statewide fire plan that the FSC had in place a diverse group of stakeholders who were well suited to undertake public comment of the plan. In response CDF encouraged the formation of locally based satellite FSCs. Between 2000 and 2005, roughly 130 local FSCs had developed in California. The communities hosting them span the spectrum from highly resource extraction-dependent communities to residential suburban interface zone communities. The National Fire Plan provoked interest among private- and public-sector organizations in this type of public–private institution, which was further facilitated by funding made available in the wake of the Plan. Increased interest combined with the large number and lack of resources for FSCs led to their incorporation and their development of policies, employee guidelines, by-laws, and administrative procedures. To coordinate the many local Councils, the California FSC Clearinghouse was created. Operated by the California FSC, the

Clearinghouse is a breakthrough program that makes funds available for community-based efforts such as education, fuels management, and fire safety plan writing, among other activities. In 2005, the Clearinghouse administered 186 subgrants from 13 sources of funding. The Clearinghouse now serves 130 local FSCs and the umbrella California FSC provides support on administering community-based organizations.

DEFINING "COMMUNITY" AND "COMMUNITY-BASED"

The definition of "community-based" in the context of fire is variable, ranging from coerced engagement, to willing participation in externally derived plans, to development of plans by the local actors themselves (Ganz, Moore, & Shields, 2001; Moore, Ganz, Tan, Enters, & Durst, 2002). Agencies involved in community fire management (governments, non-governmental organizations [NGOs], projects, and others) emphasize not only community involvement but also capacity building. Such activities may include supporting an existing community-based system through formalizing, modifying, or otherwise elaborating on it, or instituting new systems. Many of these systems and approaches are considered more effective in avoiding unwanted fires, more beneficial to local ecosystems, and more cost-efficient over the long term (Jackson & Moore, 1998; Moore et al., 2002; Ganz & Moore, 2002). A recent study on wildfire and poverty in the western United States defines community capacity as a community's ability to protect itself, respond to, and recover from wildfire (Lynn & Gerlitz, 2005).

In the global context, we can further define the criteria of community-based fire management as:

- Communities are actively involved in decision making.
- Emphasis is placed on local decision making with an assumption that objectives are formulated to receive some benefits for those within the community.
- Decision-making power does not necessarily equate to full control.
- Initiation may be by the community or by outside entities (governments – national, provincial, state, district, and local, NGOs, donors, watershed network/ Fire Safe Councils, etc.).

The definition of "community" in the context of resource management is also variable (see also Chapter 10 by Stokowski for a further discussion of how the scholarly literature addresses the concept of community in relation to resource management). Agrawal and Gibson (1999) have pointed out that the literature on community-based resource management tends to avoid analyzing precisely what is meant by the concept of "community" or how this conceptualization affects how outcomes are assessed. In their literature review they point out that it is frequently defined as a small, territorially fixed spatial unit with homogeneous social structure and shared norms. However, they point out that, in reality, communities are far more dynamic and heterogeneous, and these characteristics must be taken into account for successful management of natural resources. In particular, it is important to assume a diversity of interests and norms in any community. Highlighting this concept, in an analysis of 30 community-based resource management initiatives from around the United States, Selin, Schuett, and Carr (2000) found an average of 16.8 organizational members participating, with over 93% having involvement from federal and state government, 93% from environmental groups, 89% from landowners, 83% from local government, 79% from business, 69% from agricultural organizations, and 52% from civic groups. This diversity is also evident in the example given in Fig. 3, where an entity, considered as a single community is actually composed of diverse geographically based groups with different approaches to management. This underscores that functionally defined communities are often determined more by the extent of a group of individuals willing to act collectively rather than by a jurisdictional boundary.

In the context of fire management, "community" has been used broadly to include anything from a household or a group of households, to a settlement or a group of settlements, to a jurisdiction or set of jurisdictions. While a single household may not be considered a community, in some cases, such as in Vietnam, households have been used as important functional units in targeting community forest management and forest fire management (Pham, 1999; Hung, 2001). In California, the FSCs, which are considered to be community organizations, generally embody one county but often include two, as in the case of the Diablo Fire Safe Council (www.diablofiresafe.org), which serves 19 incorporated cities in Alameda and Contra Costa Counties and a number of unincorporated communities. With a mandate to preserve these counties' natural and manmade resources from wildfire, this FSC has served as a hub for neighborhood and community groups to coordinate with all levels of government and connect community problem solving with government resources in a way that is more accessible and more accountable.

Box 2: Case from East Kalimantan: This particular community living around Sungai Wain Protection Forest had 14 subgroups. Each of these subgroups will likely have varying knowledge and experience with fire management or perhaps none at all. Some have noted that new migrants to East Kalimantan are partially responsible for some of the harmful fires because they watched and mimicked neighbors clearing land with fire without an understanding of fire as a management tool in their new surroundings.

Fig. 3. Case from East Kalimantan.

As the technical and organizational capacity of communities in relation to managing fire, historically and culturally, is poorly understood and rarely studied, it would be very difficult to transfer lessons from one community to another without further research on the determinants of success in CBFiM.

SENSE OF OWNERSHIP IN CBFiM

There are different ways for communities to participate in fire management. Local involvement can be initiated, stimulated, and supported using a variety of social or economic incentives. Although all of these roles are important, truly sustainable community action depends on having grassroots participation in decision making and priority setting.

A sense of ownership is a key determinant for effective community participation in fire management. To be successful and achieve the long-term goal of establishing a community organization to facilitate fire planning processes (e.g., the FSCs in California) organizers need to empower the local community with a sense of involvement in the process and ownership in the outcomes. The United Nations' Agenda 21 (Chapter 7, Section 7.20) from *Promoting Sustainable Human Settlement Development* defines this sense of ownership as what "empower(s) community groups, non-governmental organizations and individuals to assume the authority and responsibility for managing and enhancing their immediate environment through participatory tools, techniques and approaches embodied in the concept of environmental care" (United Nations Division for Sustainable Development, 2004). Selin et al. (2000) found that respondents felt that "sense of belonging" was one of the strongest contributors to "effective collaboration" and that, probably related, perceived legitimacy of leadership was also a strong correlate of process effectiveness.

It is important to note that this sense of process ownership does not automatically arise from legal ownership, as absentee or investment owners may be less concerned with the process than locally based renters. There are instances where land ownership and resource access do not directly translate into a sense of ownership in the outcomes of fire management. In the case of the Quincy Library Group (QLG) in northeastern California (Fig. 4), the community concerns about fire management were ignored by state and federal government agencies until the community took collective action to demonstrate their "sense of ownership" of public lands. The QLG has since created a series landscape scale treatments, based upon the use of Defensible Fuel Profile Zones (DFPZs) and forest thinning (Kiester & Gropp, 1999).

Incentives can often facilitate this sense of ownership. Some incentives are long-term and inexpensive. Others are short-term and expensive, but still worthwhile. A closer evaluation of these incentives for a community should be addressed early on when they are convened to define and prioritize their community-specific needs and objectives. In a state like California, this approach has typically been facilitated by the FSCs. Since 1993, community members in the State of California, exasperated by lack of attention or misguided approaches to fire management by state and federal government agencies, initiated fire management planning efforts, and invited state and federal agencies to join them. While these government agencies recognize the value of participating in consultative local "FSCs," the visions of many of these local initiatives go far beyond the degree of collaboration foreseen by the agencies. As these councils began to grow throughout the State of California, the expenses for these community-based initiatives have been covered by state and federal government funds requested by the consortium

Box 3: Case from Quincy, California, USA: The Quincy Library Group burst onto the national stage on July 9, 1997, when the U.S. House of Representatives approved, 429-1, a forest management plan developed by this rural consensus coalition to manage 2.4 million acres of northeastern California's National Forest land. It was an extraordinary accomplishment for a rural group of environmentalists, timber executives, county commissioners and volunteers.

The 1999 Herger-Feinstein Quincy Library Group Forest Recovery Act established a five-year program to test how best to protect a forest and its habitat from fires and destructive logging, while still producing enough wood to keep the local timber industry alive. The emphasis in the bill was on thinning, the creation of firebreaks, and the protection of 526,400 acres of roadless areas.

Fig. 4. Case from Quincy, California, USA.

of local government and non-governmental parties, under the umbrella of the FSCs.

COMMUNICATION AND INFORMATION IN CBFiM

Essential to community-based approaches to manage fire in the urban–wildland interface and the broader landscape, is the flow of information and open means of communication. The difficulty in communicating to stakeholders is highlighted by recent research which found that residents of some fire-prone communities often only weakly support investment in fire fighting infrastructure, are unlikely to take all necessary steps to mitigate hazard around their own homes, and have highly negative attitudes towards risk-prone mitigation strategies like prescribed burning (Winter & Fried, 2000; see Chapter 5 by Menning for a further discussion of the social impediments towards prescribed burning).

There is a tendency in these fire-prone communities to get complacent or forgetful, even after a large conflagration. Several sociological studies (TSS Consultants & Spatial Informatics Group LLC, 2005; Gardner, Cortner, & Widaman, 1987; Gardner & Cortner, 1988; Cortner, Gardner, & Taylor, 1990) have found that the majority of homeowners surveyed did not believe the wildland fire situation to be serious at the time they purchased their home. In Southern California, despite having some recent fire experience, these studies have found that impacted communities express low awareness of fire hazards and a belief that fire would not reoccur in the area. Their findings indicated that recent wildfire survivors tend to discount future wildfire risk because they are convinced that fire will not strike twice in the same place. This is generally consistent with the results of Chapter 6 in this volume by Troy and Romm, which found that homes in Very High Fire Hazard Severity Zones (where transfer disclosure of fire hazard is required under statute) in California actually sold for *more* than comparable homes outside of these hazard zones. Statutory hazard zone homes only sold for less than comparable non-hazard zone homes when located near the site of a major recent conflagration.

Communication and outreach efforts are therefore essential to effective CBFiM, not only for generating support for potentially risky mitigation strategies, but even for motivating residents to undertake low-risk mitigation strategies, like maintenance of defensible space. Several studies have found that educational outreach efforts can increase support for prescribed burning (Loomis, Bair, & Gonzalez-Caban, 2001; Toman, Shindler, & Brunson, 2006). Toman et al. (2006) further attempted to determine what outreach techniques and approaches are most effective. In studying eleven fuel management community outreach programs in four western states, they found that those that were most effective in generating support displayed a number of characteristics. First, interactive outreach methods were far more effective than unidirectional ones. This is partly because a unidirectional approach often fails to account for stakeholders' personal experiences and how they relate to the problem. Second, problem-based information dissemination, focused on the immediate surroundings was more effective than generalizations. This is consistent with previous research which has found that people specifically seek out information on how resource management will affect them directly, as well as the places they know and care about (Wondolleck & Yaffee, 2000). Third, outreach was more effective when characterized by a sense of trust. While the concept of trust is difficult to quantify and no formula exists for generating it, the authors suggest that outreach processes with a component of personal relationships and two-way information flows will be most successful.

COMMUNITY WILDFIRE PROTECTION PLANS IN THE WESTERN UNITED STATES

At the behest of the United States' Congress, the Western Governor's Association worked together with a group of stakeholders to produce *A Collaborative Approach for Reducing Wildland Fire Risks to Communities and the Environment: A 10-Year Comprehensive Strategy* in 2001, and its companion document, the *Implementation Plan*, in 2002 (Western Governor's Association, 2002). These led to the passage of the Healthy Forests Restoration Act (HFRA) in 2003, in which communities have been charged with becoming active partners in their own protection from wildfire.

The HFRA is unique in that it has recognized the importance of community involvement in forest planning. Under this legislation, communities prepare CWPPs in collaboration with state and local officials, identify prominent sources of fire risk, summarize structural ignitability concerns, and prioritize areas for fuels reduction treatment. These activities continue to be a strong area of focus for the U.S. Department of Agriculture's Forest Service and the U.S. Department of Interior's Bureau of Land Management. Both of these organizations are working with community leaders, including conservation districts and resource, conservation, and development councils, to construct and implement CWPPs. The plans address issues such as wildfire response, hazard mitigation, and community preparedness in a collaborative fashion. The main purpose of CWPPs is for localities to improve their wildfire mitigation capacity and to work with government agencies to coordinate efforts to identify high fire risk areas and prioritize them for mitigation, suppression, and emergency preparedness management. States play a key role in the formulation of CWPPs, as communities may look for long-term guidance from outside experts. In June 2003, the National Association of State Foresters directed state governments to identify and prioritize communities at risk; this was done as a follow-up to the Federal Register list of Communities at Risk developed in 2001 (National Association of State Foresters, 2003).

A clear examination of how community characteristics relate to approaches to fire management is necessary to further promote CWPPs in the United States. Traditionally underserved and low capacity communities may have few internal resources available to prepare for and respond to crisis and change. Efforts that seek to provide community assistance may fail to succeed in low capacity communities because they may require different types of assistance (Lynn & Gerlitz, 2005). An assessment tool is needed to understand existing approaches for community capacity building in managing fire and responding to emergencies. Also needed is a standardized framework for defining "communities at risk" (CAR) which, up until now, has been problematic (National Association of State Foresters, 2003). Following Congressional direction, each state, in consultation with tribes, compiled a list of communities in the vicinity of federal land that are at high risk from wildfire. Lists were published in the Federal Register (66 Fed. Reg. 753, January 4, 2001); language there acknowledges that states' lists were compiled using different criteria, reflecting the varying needs and values of the individual states, and are considered incomplete and in need of ongoing updates. As a result, most agree that there is a great deal of variability in the lists as states have defined community and risk differently. Many have noted that there is ultimately little value in developing a national list as the geographic and socio-political variables differ so vastly in each state.

The CWPP process also varies considerably between states. There is not a one-to-one correspondence of Plans to communities protected; many individual Plans cover more than one community, and in some cases a large community may have sub-divisions that have their own Plans. States differ in the resource availability for CWPP development, and individual communities have tremendous variability in development and implementation capacity, including level of citizen skill and awareness, finances available, and access to technology such as Geographic Information System (GIS) to assist with fire safe planning (see Chapter 11 by Radke for a discussion of computer-based fire mitigation planning technology).

Despite these challenges in CWPP development and fire mitigation capacity, the western United States is clearly moving toward increased community protection through the CWPP process. Identifying local concerns and prioritizing protection activities not only serve to attract agency attention to fire management needs, but they also serve as the basis for sound plans which in turn increase community capacity and heighten awareness of local fire risk and responsibility. All states are currently compiling or have already finalized their CAR list, and many have begun regular updates to keep the list current. Every state has begun the process of creating CWPPs, although rates of completion vary considerably. Across the western United States, 329 CWPPs have been completed and approved as being in accordance with HFRA guidelines. Countless additional planning documents serve to protect communities and counties. As communities and states begin to share success stories and lessons learned, this will only serve to make this model more accessible to other communities; already, templates and field guidance have been developed by a number of non-profit, government, and research entities to facilitate the process.

Many who have been involved in CWPP development note that the process is itself a success. Fire planning collaboration among local landowners, local governments, land management agencies, and states creates lasting relationships that extend beyond the immediate task. These networks are invaluable for information sharing and community capacity building, even beyond natural resource management. Throughout the western United States, there is enthusiasm for improving such collaborative efforts so as to protect communities and develop strong fire management planning processes.

In addition to facilitating the multiple stakeholder forums needed to prepare a CWPP, it is important for communities to utilize this process to approach the following goals:

- Protecting against potential losses to life, property, and natural resources from wildfire.
- Building and maintaining active participation from each Fire Protection District.[2]
- Setting realistic expectations for reducing wildfire risk.
- Identifying and prioritizing actions for fire protection and mitigation on private and public land.
- Pursuing federal and other grant dollars.
- Identifying incentives for private landowners to participate in fire protection.
- Promoting visible projects and model programs.
- Monitoring the dynamic conditions of wildfire risk and how these projects and programs raise awareness.
- Institutionalizing fire-related programs and sustaining community efforts for fire protection.

Quantifying effectiveness of the CWPP process and other community-based approaches in the wildland–urban interface is a challenge as there is no standardized system of evaluation. This is partly because of the very different ecological and socio-economic contexts of each community. In January 2004, the National Academy of Public Administration (NAPA) published a report with recommendations on reducing national wildfire suppression costs, in response to a request from Congress. The report concludes that the greatest cost-reductions can be gained not by increasing efficiency of suppression efforts, but through "reducing wildfire hazards on a broad scale before a fire begins" (NAPA, 2004, p. 3–4). It recommends working at a "landscape scale" to reduce fire hazard through three mechanisms, including reduction of fuel loads, creation of fire breaks and creation of "fire-resistant communities and defensible spaces (places that are less prone to burn because of precautions taken ahead of time)" (p. 4). It then goes on to recommend that achieving this end requires a collaborative approach:

> "Each of these hazard reduction strategies is complex to implement. Their success requires science-based assessments, collaborative planning, and coordinated actions by many different parties. Last year, we recommended a more collaborative approach, and this year we have explored in greater detail what that approach would look like organizationally and operationally. In this report, we address interagency and intergovernmental collaboration, as well as public private linkages, and how they can bring together all of the stakeholders who are essential to success in a way that will best enable them to build the capacity they need to succeed." (p. 4)

CHALLENGES TO INSTITUTIONAL SUPPORT AND IMPLEMENTATION

Despite these efforts, the CWPP process, other community-based approaches, and the larger field of CBFiM lack clarity and subsequently sufficient institutional support. A very symptomatic example in the United States is the inability to clearly define a "community at risk". In other parts of the world, the community may be well defined but the collaborative framework or participatory approach is poorly supported. Although the linkages with community based natural resource management (CBNRM) and community forestry have continually been emphasized and strengthened, there is still wariness by institutions that promote these processes that the addition of the fire management issue will potentially splinter an already diffused group of CBNRM disciplines. Since the beginning of the dialogue on CBFiM, it was stressed that CBFiM has to be undertaken within the context of overall land use planning (see Chapter 3 by Paterson for a discussion of how fire safe planning fits into "smart growth" land use planning) and natural resource management (Jackson & Moore, 1998, Ganz et al., 2001). Rather than taking on an independent identity, CBFiM was to be a component of a larger community capacity building process. CBNRM has been successful at transitioning from a field of interest to institutional implementation. A simple web search demonstrates that a large number of research centers are involved in this field with independent research programs, forums, and/or support networks like those provided by the Regional Community Forestry Training Center (RECOFTC),[3] the Community-Based Natural Resource Management Network[4] and the Community-Based Natural Resource Management Asia Virtual Resource Center.[5] CBNRM has also been integrated into education and training which recognizes the technical and organizational capacity of communities in relation to managing natural resources. For CWPPs and CBFiM to advance fire management in a similar fashion, it will need to develop rapid appraisal and assessment tools to characterize its community based approaches with consistency and rigor.

A fundamental principle behind a community-based approach such as the FSCs and CWPPs is that key stakeholders need to be identified and understood so as to plan more effective interventions. For instance, preliminary investigations should attempt to determine which stakeholders are most cooperative, which are most combative, what level of clout they have with the community, and what interest or set of interests they represent. As part of this process, effective leaders with local legitimacy should be sought if they do not emerge, following on the findings of Selin et al. (2000).

Interventions also need to be evaluated and tracked to ensure that resources are directed in sufficient quantities to underserved communities. In the United States, there are limited data on the extent to which grants have been awarded or successfully implemented in low-income and low-capacity communities; agencies providing support should take into consideration that financially stressed communities may need additional resources and distinct programmatic approaches to reduce wildfire risk. This may include a review of how well underserved, impoverished, or lower capacity communities are being helped to develop community wildfire protection plans and a review of the implementation of new methods or programs to assist these communities.

There has been concern that the CWPP process is often hijacked by commercial interests. Many environmental groups worry that CWPP and other place-based collaborative processes are merely a means for sidestepping the regulatory burden (Axline, 1999; Hibbard & Madsen, 2003), a view seconded by a number of unpublished reports.[6] There is a particular concern about processes designed to manage public lands since they are owned by the public at large, regardless of location, while local commercial interests will have far greater incentive to get involved (and, some fear, co-opt the process) than the at-large public, who are likely to benefit from these public lands in very different way from the commercial interests. Therefore, it is imperative that all community-based processes be transparent and, particularly where public lands are involved, open to a wider public constituency.

CONCLUSION: THE CURRENT STATE OF KNOWLEDGE AND NEED FOR FUTURE RESEARCH

In addition to reducing the potential financial drain of concentrating solely on suppression-focused fire management strategies, a movement towards CBFiM will also help governments to resolve institutional conflicts that have inhibited forest conservation and the sustainable utilization of natural resources. The fundamental elements of institutional change needed in fire management include:

- A shift in the locus of control from central government to the local level.
- A change in the institutional framework within which fire management is administered, from national and state institutions to local institutions (such as FSCs, Fire Districts, and community organizations).
- A recognition that forests and wildlands cannot satisfactorily be retained, conserved, or managed by governments without considering the potential impacts – positive or negative – of fire on local institutions and communities.
- A change in the conceptual framework within which fire management is conceived and developed, away from the dominance of national/state or commercial concerns towards one that acknowledges and supports the capacity of local institutions to plan and manage desired fire collaboratively, while preventing and reducing the destructive effects of unwanted fires.
- A change in the mode of day-to-day forest fire management, away from conflict-inducing regimes of regulatory police power, towards one in which the local user is both self-regulating and partly responsible for protection activities.

- A shift in forestry and fire management academic/training institutions, away from training foresters and resource managers as technical experts towards training facilitators to broker collaborative management arrangements between villages, local institutions, and government agencies.
- A range of supporting activities to promote institutional change, including: policy reform; enabling legislation; institutional development and capacity building at the most local level; CBFiM authority and implementation; and investment in documentation and public awareness campaigns for communicating the efficacy of these approaches.

In conclusion, the interrelation between wildfire management and community institutions cannot be ignored. This review has identified that people around the world are concerned to different degrees about living with fire. Fire is not something that can be excluded from the daily lives of many communities. The connection between communities and fire is often through an economic base (structures, assets, livelihoods, commercial activities, and impacts) and in the longer term, through public health. An examination of communities and stakeholders and their approaches to fire management is necessary to promote CBFiM at higher levels. This would serve as the basis for clarifying objectives to move ahead with constructive dialogue between interested parties on how to manage fire in the landscape.

Lynn and Gerlitz (2005) suggested that case studies be performed in different regions of the United States in high wildfire risk areas to gain a better understanding of the relationship between wildfire and community capacity. These case studies should be designed to provide an in-depth analysis of wildfire risk, socio-economic status, and the capacity of local communities as well as more information on how well grants and resources are assisting low-income communities. Ganz, Fisher, and Moore (2003) have developed a series of rapid appraisal tools that would assist in developing these case studies with a systematic and rigorous design that also allows for comparisons amongst different regions of the United States and other parts of the world.

In reviewing the mechanisms by which communities are involved in fire management, one should recognize the dynamic nature of the world and its changing actors. No one actor, whether part of government or civil society, can achieve a solution to the serious social, economic, and ecological threat of wildland fires. It is essential that constructive partnerships are formed at the community level between residents, governments, the private sector, and community institutions. This review of the mechanisms of participatory fire management processes is a necessary first step to recognizing the role of communities in managing fire. It identifies many ways in which communities take action in fire management and points out how these actions could be even more effective if local partnerships had more credibility. Due to their limited power, such partnerships cannot always manage for fire mitigation without help from state and federal government. In addition, this review has suggested some possible comparisons that might be necessary to move beyond the examples to actual system elements. These system elements may be useful to governments at all levels as well as international actors as they seek more cost-effective alternatives to managing fire in an increasingly fire prone world.

NOTES

1. While acknowledging the roles that governments have played in the past as forest conservators (mainly through the creation of reserves), there is also a growing recognition that government agencies have not ultimately proved the most effective agents for preserving forests. Even where government entities have successfully managed forests for conservation objectives, they have not always done so in the most participatory manner.
2. Fire Protection Districts are departments within a municipal government that are responsible for preventing and putting out fires. "District" means an agency of the state for the local performance of governmental or proprietary functions within limited boundaries.
3. RECOFTC network (http://www.recoftc.org).
4. Community-Based Natural Resource Management Network (http://www.cbnrm.net/).
5. Community-Based Natural Resource Management Asia VRC (http://www.cbnrmasia.org).
6. Such as the Highway 17 Forum (http://www.hiway17.com/forum_viewtopic.php?8.189) and Middle East Fork Project (http://www.fs.fed.us/r1/planning/final_appeals/bitterroot/objection_summary_spar_0013.pdf).

REFERENCES

Agrawal, A., & Gibson, C. (1999). Enchantment and disenchantment: The role of community in natural resource conservation. *World Development*, *27*, 629–649.

Axline, M. (1999). Federal lands and invisible hands. *Ecology Law Quarterly*, *25*, 611–623.

Castillo, A. (2001). Community-based fire management with a watershed subproject in a remote area in the Philippines. In: D. Ganz, P. Moore & B. Shields (Eds). *Community based fire management regional workshop, December 6–8, 2000*. Regional Community Forestry Training Center, Bangkok, Thailand. RECOFTC Report 19. 87 p.

Cortner, H. J., Gardner, P. D., & Taylor, J. G. (1990). Fire hazards at the urban-wildland interface: What the public expects. *Environmental Management*, *14*, 57–62.

Ganz, D. J., Fisher, R. J., & Moore, P. F. (2003). Further defining community-based fire management: Critical elements and rapid appraisal tools. In: *Proceedings of the 3rd international wildland fire conference*, October 2003, Sydney, Australia.

Ganz, D. J., & Moore, P. F. (2002). Living with fire. In: P. Moore, D. Ganz, L. C. Tan, T. Enters & P. Durst (Eds), *Communities in flames: Proceedings of 1st international conference on community involvement in fire management*. FAO RAP Publication 2002/25, 133 p (pp. 1–9).

Ganz, D. J., Moore, P. F., & Shields, B. J. (2001). Report of an International Workshop on: Community Based Fire Management. Organized by RECOFTC & Project FireFight South East Asia, Kasetsart University, Bangkok, Thailand. 6–8 December 2000.

Gardner, P. D., & Cortner, H. J. (1988). An assessment of homeowners' perceptions of wildland fire hazards: A case study from southern California. In: E. E. Whitehead, et al. (Eds), *Arid lands: Today and tomorrow* (pp. 643–657). Boulder, CO: Westview Press.

Gardner, P. D., Cortner, H. J., & Widaman, K. (1987). The risk perceptions and policy response toward wildland fire hazards by urban home-owners. *Landscape and Urban Planning*, *14*, 163–172.

Healthy Forest Restoration Act of 2003. Public Law 108–148. 108th Congress.

Hibbard, M., & Madsen, J. (2003). Environmental resistance to place-based collaboration in the US West. *Society and Natural Resources*, *16*, 703–718.

Hoare, P. (2004). A process for community and government cooperation to reduce the forest fire and smoke problem in Thailand. *Agriculture, Ecosystems and Environment*, *104*, 35–46.

Hung, P. N. (2001). Assessment of the forest fire situation (1998–2000) and community-based forest fire management for biodiversity conservation in Vietnam. In: *Proceedings of Workshop on minimizing the impact of forest fire on Biodiversity in ASEAN* (pp. 117–120), Brunei Darussalam. 22–23 March 2001. Retrieved from www.arcbc.org.ph/new/workshops/regional/proceedings/sea_22_03_01.htm.

Igsoc, R. O. (1999). Appropriate mission and structural organization concerning forest fire management, the Philippines, *Conference paper of the Second International Workshop on Forest Fire Control and Suppression Aspects*, Bogor, Indonesia, February 1999 (pp. 16–21).

Jackson W. J., & Moore, P. F. (1998). *The role of indigenous use of fire in forest management and conservation. International Seminar on Cultivating Forests: Alternative Forest Management Practices and Techniques for Community Forestry*. Regional Community Forestry Training Center, Bangkok, Thailand, September 1998.

Jurvelius, M. (2004). Community-based fire management in southern Africa. *Unasylva*, *55*, 3.

Kiester, E., & Gropp, G. (1999). A town buries the axe (The Quincy-Library-Group brings together people in a California community who were bitterly split over logging). *Smithsonian*, *30*, 70–79.

Loomis, J., Bair, L., & Gonzalez-Caban, A. (2001). Prescribed fire and public support: Knowledge gained, attitudes changed in Florida. *Journal of Forestry*, *99*, 18–22.

Lynn, K., & Gerlitz, W. (2005). *Mapping the relationship between wildfire and poverty*. Report from the National Network of Forest Practitioners, Resource Innovations at the University of Oregon, and the United States Department of Agriculture Forest Service State and Private Forestry, Cooperative Programs and Research and Development, 50 pp.

Makarabhirom, P., Ganz, D. J., & Onprom, S. (2002). Community involvement in fire management: cases and recommendations for community-based fire management in Thailand. In: P. Moore, D. Ganz, L. C. Tan, T. Enters & P. Durst (Eds), *Communities in*

Flames: Proceedings of first international conference on community involvement in fire management, FAO RAP Publications 2002/25 (pp. 10–15).

Moore P., Ganz, D., Tan, L. C., Enters, T., & Durst, P. B. (Eds). (2002). Communities in Flames, *Proceedings of first international conference on community involvement in fire management,* Food and Agriculture Organization of the United Nations and Project FireFight South East Asia.

National Academy of Public Administration (NAPA). (2004). *Containing wildfire fire costs: Enhancing hazard mitigation capacity*. Washington DC: NAPA January 2004.

National Association of State Foresters. (2003). Field Guidance: Identifying and Prioritizing Communities at Risk. Retrieved from http://www.stateforesters.org/reports/COMMUNITIESATRISKFG.pdf.

Pham, N. G. (1999). *Community-based forest fire management for biodiversity conservation in Vietnam*. Paper presented at the Proceedings of First International Workshop on National Guidelines on the Protection of Forests against Fire, March 1999, Bogor, Indonesia.

Selin, S., Schuett, M., & Carr, D. (2000). Modeling stakeholder perceptions of collaborative initiative effectiveness. *Society and Natural Resources*, *13*, 735–745.

Toman, E., Shindler, B., & Brunson, M. (2006). Fire and fuel management communication strategies: Citizen evaluations of agency outreach activities. *Society and Natural Resources*, *19*, 321–336.

TSS Consultants, & Spatial Informatics Group LLC. (2005). *Assessment of the Efficacy of the California Bureau of Land Management Community Assistance and Hazardous Fuels Programs*. Report to the U.S. Bureau of Land Management, pp. 1–81.

United Nations Division for Sustainable Development. (2004). *Promoting Sustainable Human Settlement Development*. Agenda 21, Chapter 7. Retrieved from http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21chapter7.htm.

Western Governors Association. (2002). *A collaborative approach for reducing wildland fire risks to communities and the environment: 10-year comprehensive strategy implementation plan*. 27 p. Retrieved from http://www.westgov.org/wga/initiatives/fire/implem_plan.pdf.

Winter, G., & Fried, J. (2000). Homeowner perspectives on fire hazard, responsibility, and management strategies at the wildland-urban interface. *Society and Natural Resources*, *13*, 33–49.

Wondolleck, J. M., & Yaffee, S. L. (2000). *Making collaboration work: Lessons from innovation in natural Resource management*. Washington, D.C.: Island Press.

CHAPTER 10

HUMAN COMMUNITIES AND WILDFIRES: A REVIEW OF RESEARCH LITERATURE AND ISSUES

Patricia A. Stokowski

In recent years, the incidence and severity of wildfires across the United States has given the topic new public and academic salience. The occurrence of wildfires across rural and remote land areas ''out West'' has always been expected – but large, intense, dangerous fires have become more common in rural and rural/urban interface areas around the country. The need for scholarly study as well as practical advice relating to wildfire hazards, fire preparedness activities, and management and mitigation strategies, is evident.

In general, the academic literature about wildfires has attempted to provide both scholarly and applied perspectives, though it tends to feature highly practical research and reports that address managerial and public problems associated with wildfires. Published articles and scholarly discussions typically center around topics such as wildfire threats to homes and structures; fire hazard identification; agency and public perceptions of risk related to wildfire disasters; homeowner coping behaviors and landscape preparedness measures; strategies (usually financial, restorative, and precautionary) for mitigation efforts after wildfire events; and attitudes about policy and management alternatives aimed at preventing future fire

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damage. Though social scientists are becoming more visible in research arenas related to wildfire problems, Cortner and Field (2004, p. 474) even recently observed that, "there is scant research about the social impacts of fire events."

Published research studies about social aspects of wildfire problems have traditionally focused on either individual or institutional levels of analysis. Studies about the psychological orientations and behavioral responses of individuals (homeowners, resource managers, local government officials) have predominated, as Field and Jensen (2005, p. 355) observed: "Social science research has begun to address the interaction of humans, fire, and forests, but the majority of studies currently underway focus on individual human behavior." For example, Kneeshaw, Vaske, Bright, and Absher (2004) used a mail survey of visitors to national forests in Colorado, Washington, and California, to focus on public attitudes and perceptions of wildland fire management. Similarly, using interview techniques and multiple methods, Kumagai, Bliss, Daniels, and Carroll (2004) studied attributions of blame made by individuals who had experienced wildfires in communities along the Sierra Nevada Mountains of California.

Institutional-level studies tend to focus on policy issues and organizational responses to wildfire dangers (e.g., Brooks et al., 2006; Steelman & Kunkel, 2004), particularly those involving government practices associated with wildfire prevention and/or management (many wildfires either begin on public lands, or spread to them, making federal agencies partners with local communities in wildfire situations). Among these studies are analyses aimed at understanding problems or failures in agencies, public communications or actions, and studies dedicated to improving local and regional preparedness and mitigation efforts. Often these studies propose government-sponsored educational and assistance programs aimed at informing individual homeowners or key leaders at the community, organizational, or state level – a top-down approach to problem solving.

Whether individual or institutional in nature, wildfire studies that focus on people (rather than ecology) tend to have in common an implicit observance of "community." In this literature, a human "community" is defined primarily (though often indirectly) as a place with geographic boundaries and political-economic organization. In practical terms, communities are assumed to offer generalized settings for managing wildfire problems that extend beyond individual homeowners or renters, and beyond governmental control or coordination. The fact that communities are places where people live, work, and play is assumed to have immediate relevance for wildfire management.

But, the focus on "community as a locale" has only limited utility for advancing social science research related to wildfires. As sociologists have observed, community is a concept with many meanings – but many definitions of community assume at least three elements: "people living within a specific area, sharing common ties, and interacting with one another" (Lyon, 1987, p. 5). Communities are aggregations of people linked by sentiment, belongingness, interest, or affiliation – and sometimes, they even involve people who are not all located in the same geographic place (think of "communities of scholars," for example). Moving beyond basic geographical definitions to include analyses of community social interactions, relationships, and processes expands the focus and usefulness of community research in wildfire studies (see Chapter 9 by Ganz et al. for additional discussion on defining the term "community" in the natural resource context).

A broader theoretical approach to conceptualizing community would allow researchers to explore the characteristics and types of social interactions and social organization that constitute community, and to consider the consequences of community relationships for individual and social behaviors related to wildfires and their management. How community residents interact with one another under threat of fire, how forest managers sustain connections with local leaders, how emergency personnel sustain ties of community under stress, whether visitors and tourists are linked by affiliation or sentiment to a geographic area and its residents, are but a few of the interesting questions that should be studied in gauging the success of wildfire education, preparedness, and management programs.

The purpose of this paper is to evaluate the state of research on the topic of community in wildfire contexts, especially as that research relates to community relationships and interactions that may support more effective preparedness for, and mitigation of, the effects of wildfires. The literature in this area does not yet constitute a coherent and forceful body of work on the topic, but instead, diverges widely, with some studies only peripherally related to the topic, and others primarily hypothetical. A review of this literature, though, provides a snapshot of the current state of research about communities and wildfire, and allows researchers to consider opportunities for expanding this body of work. In this review, three specific topics will provide an organizing framework: the formal relationships and inter-organizational ties developed from wildfire planning and management as these practical applications relate to communities; the informal social relationships of community that are directly related to wildfire contexts; and communication and outreach programs related to community and wildfires. The discussion section outlines some future research needs in these and other areas of study.

FORMAL COMMUNITY RELATIONSHIPS: NETWORKS OF STAKEHOLDERS

Wildfire researchers have typically focused on the formal social relationships and organizational structures of community and community leadership in analyzing fire preparedness and planning. This may be reasonable given the policy positions of natural resource agencies charged with management of wildfires on large public lands, particularly in the American West. When fires are allowed to burn on public lands, there are inherent risks to communities located in the path of the burn. Formal relationships between federal and state agencies and local communities (particularly with local government leaders and other people in positions of authority and power), therefore, are critical in maintaining clear communications, in reducing potential dangers, and in providing appropriate responses when wildfire dangers occur. The scholarly research in this area has a clearly applied focus, and much of it also has a ''top-down'' orientation that reflects the resource agency funding that underwrites this work. The relevance is clear: resource managers are charged to identify persons and groups ''with a stake'' in the outcome of resource management policies, and to evaluate the outcomes of agency-designed educational and outreach programs for affected publics.

An example of this type of research is a report about the 2003 fires in southern California, which were some of the most devastating in that state. These fires caused 24 deaths, burned over 3,600 homes, and scorched nearly 740,000 acres (Sellers, 2004). Their consequences led the California governor to appoint a Blue Ribbon Fire Commission, which offered a variety of suggestions for coping with future fire dangers. In response, several multi-agency and multi-jurisdictional groups were formed to integrate efforts aimed at wildfire preparedness, response, and recovery efforts. Supporters of these collaborative efforts have suggested that their success ultimately depends on the interconnectedness of individuals, communities, agencies, private groups, and businesses – connections that, if effective, lead to increased trust, creativity, and mutual satisfaction, in wildfire preparedness and mitigation efforts as well as in other community initiatives. The impact of these collaborative efforts is an issue that deserves further research attention.

In studying wildfire effects in the urban/wildland interface areas near three national forests, Vogt and Nelson (2004, p. 13) similarly suggested that local social institutions should be actively involved in ''Creating neighborhood and community support for larger initiatives in the community to reduce risks associated with wildfire.'' They recommended that community initiatives involve a variety of stakeholders, including Realtors® who facilitate home purchases in the urban/wildland interface; local government leaders who manage property transfer and taxation processes; local schools, developers, and builders; and other private entities. Such efforts would foster collaborative approaches to create and sustain horizontal linkages of support and communication within and across communities.

Their comments are echoed by Burns, Sperry, and Hodgson (2003), who support community efforts to build stakeholder networks that would be instrumental in facilitating community education, fire planning and preparedness, and longer-term resource stewardship. Based on their research in western Colorado, these authors suggest that such networks should be built strategically to include community leaders (government officials, conservation experts, emergency management personnel, local media, and others), resource agency personnel (forest and fire managers in a variety of agencies), and citizens interested in or having a stake in wildfire management (Realtors®, educators, civic group representatives, and so on).

These concerns are echoed in a Colorado workshop that focused on fire management in urban/wildland interface areas. This workshop brought together agency personnel, researchers, and community leaders concerned with wildfire preparation, management, and mitigation (Brooks, Champ, & Williams, 2004). A central topic of interest to participants was that of how to effectively work with communities that might be threatened by wildfires, and how to account for their unique social and ecological characteristics. Workshop participants expressed the belief that agency-initiated wildfire management efforts directed at individual homeowners and renters are not as effective as developing longer-term relationships with community leaders and residents. They concluded that efforts to build community capacity should come from fostering longer-term, substantive relationships with local people – not simply from teaching individuals about fuel reduction strategies around their own homes. Such relationships would produce higher levels of trust and interaction, and would ultimately lead to greater success in wildfire preparation efforts (the importance of trust and ''buy-in'' in community-based wildfire management is also discussed in Chapter 9 by Ganz et al., in this volume).

The managers and scientists at this workshop noted several difficulties, though, in developing stronger relationships with community members. Identifying and working with community leaders, for example, is difficult when local political leaders move in and out of office, and when fire management practitioners experience job turnover. Targeting appropriate publics with outreach and education efforts is a special challenge for resource managers trained in technical aspects of forest and wildlife management. On-the-ground agency personnel, though, have extensive local knowledge and experience, both of which are invaluable in developing successful fire management outreach programs. Social science research could help in providing information and tools that may be generalized across at-risk communities.

Researchers have also postulated that community social networks are important in the post-fire community recovery process. For example, in a study of the after-effects of wildfires in the Bitterroot Valley in western Montana, Halvorson (2002) noted that recovery assistance came from a variety of formal and informal sources: governmental and non-governmental agencies external to communities (Federal Emergency Management Agency (FEMA), State agencies, religious and non-profit organizations, Red Cross, and so on), as well as from community-based formal and informal networks (churches, school groups, environmental organizations, women's groups, the business community, and so on). She observed that, "The connection of these networks and people … resulted in a unique culture of response … . The sense that residents had of themselves as being part of a larger community was fundamental in the response and recovery process" (p. 8–9).

The nature of inter-organizational linkages across various types of formal and informal social groups and organizations, and the contributions of such relationships in providing significant emotional and tangible support and resources for individuals and families in disaster recovery, is a topic worthy of further study. Researchers and policy analysts continually point out the need to establish multi-faceted, strong relationships between agencies and communities, and note that many different types of groups (media, fire managers, resource managers, local government officials, recovery organizations, and so on) must be included. How these relationships are formed and nurtured over time will influence whether communication efforts and assistance programs are successful when emergencies arise.

A SENSE OF COMMUNITY: INFORMAL SOCIAL RELATIONSHIPS

Applied work in wildfire management has typically focused on the abilities of individual citizens to make their properties and areas around their homes safer and more resistant to wildfires. But, resource managers and local officials find it difficult as well as time-consuming to work individually with homeowners and residents. Thus, efforts have been made to develop educational and safety programs that address the fire-safety efforts of communities as a whole. Most of the research and practical work related to community preparedness for wildfire begins with a geographic notion of an affected community, typically conceived as a relatively distinct locale or place that is politically, economically, and socially organized into a town or city unit. Even if wildfires are unpredictable in scope and consequence, they are ultimately "fixed" in space, affecting some specific places but not others. But, geographic approaches to community fail to consider the dynamics of community social systems that may have importance for whether wildfire management problems are resolved.

An important quality of local social systems is the patterning of informal social ties of community – those ties of friendship and mutual support that exist between and among local citizens and visitors, and that are not based solely on people's roles in positions. Jakes et al. (2003) discussed the social foundations of community support for wildfire preparedness efforts, focusing primarily on informal social relationships. These authors suggested that communities with satisfactory levels of social capital (strong local leadership, and functioning neighborhood and interest groups), human capital (the knowledge of individuals), and cultural capital (a sense of place, and local resource management traditions), along with formal agency involvement, would more effectively prepare for wildfires. This work is speculative, but it raises important questions. Are wildfire preparedness, education, and mitigation programs more effective in communities where residents have higher levels of social connectedness and social support? Future research in applied settings will be important in providing answers to this question; researchers might begin by looking at the effects of new techniques of neighborly association and interaction (the proliferation of neighborhood email forums, for example).

Another aspect of community success in preparing for and dealing with wildfires is how general levels of community conflict and cohesion affect fire management efforts. Carroll, Cohn, Seesholtz, and Higgins (2005) studied community cohesion and conflict related to Arizona's 2002 Rodeo-Chediski fire. In analyses of social behavior in three community clusters impacted by that fire, researchers found that residents "pulled together" during and after the fire, assisting firefighters, friends, and neighbors in providing for tangible needs (food, shelter, clean-up assistance). But, instances of community conflict – based on perceptions of fairness and equity in providing disaster assistance resources, on impressions of external agency responsiveness to local situations, and on assessment of blame related to causes of the fire – were also prominent. The authors noted that, "Response to disaster events is not simply a matter of *individual* perception or action … (but is also) a function of *sociological* dynamics and depends on particular circumstances at the community level" (p. 303). They also suggested that, "Future research should attend to how local and extra-local institutions and practices are remodeled in the aftermath of catastrophic wildfire" (p. 317).

While researchers sometimes use the term "community response" to wildfires, it is not always clear what that phrase means exactly, who comprises "the community" under consideration, and what social processes are implicated in community-level interactions and relationships. One fruitful avenue for future research may be in developing an understanding of a community's sense of itself – that is, how people define themselves collectively – and what the implications of their shared sentiments are for social behavior. As Cox (1998, p. 136) wrote about a bushfire recovery process in Australia, "The sense that the town had of itself as a community was fundamental in the recovery process … . (Townsfolk knew that they had) to provide support for each other … . Many of (the community support structures) are formal or informal networks and organizations formed and sustained by community women." The work associated with local activism, organization, education, and support-giving is a theme expressed in many disaster-related sources – and it is reasonable to hypothesize that such efforts may be more successful when people see themselves as integral participants in the collaborative entity known as "their community," a tangible and emotional place that has permanence and meaning for people.

COMMUNICATION AND EDUCATION

The topics of community education and outreach, emergency information programs, and mass media effectiveness related to wildfire preparedness and response, have received considerable attention in the research literature. Social science researchers studying education and communication issues related to wildfires have tended to focus on the decision-making and coordination activities of natural resource agencies preparing fire-safety programs. These studies tend to be technical in nature and prescriptive in focus. Typically, the research results in recommendations for agency-led program design and implementation, generally focused on methods to inform citizens about wildfire dangers, or mechanisms for assuring public access to timely and useful information. Machlis, Kaplan, Tuler, Bagby, and McKendry (2002) identified three general types of research work related to communication and education about wildfire hazards: studies about organizational capacity and decision-making; community/agency interactions; and public involvement processes in decision-making.

For example, the interconnections between agencies, publics, and media were discussed in research related to two wildfires in California's San Bernardino Mountains (Pacific Southwest Research Station, 2004, p. 1). The authors of that report noted that urban/wildland interface fires raise many issues of communication, particularly for contacts within and between resource management agencies and the various publics they serve. In particular, the authors point out three key concerns: residents of fire-prone communities need accurate and timely forest fire information that is targeted to their specific geographic areas; community information systems need stability during times of transition during and after the fire; and informal communication networks are central in facilitating citizen responses to fires and fire danger. In another example, Lynn and Hill (2006) evaluated community preparedness relative to the 2005 Deer Creek fire in Oregon, and offered recommendations for education, outreach, and citizen participation strategies that would increase future awareness of local fire dangers. Many of these activities involved informal community organizations, citizens, and volunteers, as well as local government and resource agency leaders and fire managers.

Communication programs created and/or promoted by natural resource agencies are thought to work most effectively through community-based social networks – structures of formal and informal local social ties that go beyond simply informing people in positions of authority and power. For example, Taylor, Gillette, Hodgson, and Downing (2005) studied communication before, during, and after urban/wildland interface fires in southern California. They concluded that for shorter-term fires, local informal communication networks (those based on personal ties with neighbors, friends, and emergency service personnel) were very effective. For more severe and longer-term fires (and in post-fire recovery transitions), though, evacuations tended to disrupt local informal communication networks; information flow was interrupted or delayed, and communicative effectiveness was curtailed. The authors recommend that fire managers "inform the network" broadly (not simply tell local leaders) with updated and accurate information, using a variety of personal and mass media channels for greatest communicative success.

Brooks et al. (2004) reinforce this point in discussing whether and how publics and experts differ in their understanding of wildfire risks and fuels management programs. Actions related to developing community-level capabilities for mitigating wildfire risks are seen as key in successful wildfire management. The authors note (p. 2) that, ''The readiness of a community to mobilize and begin fuel reduction projects may often depend on how long they have been talking about the issue between themselves and outside partners.'' Forest managers and wildfire experts can contribute to community preparedness by engaging in regular interactions with local leaders who live in at-risk communities. Partnerships will likely build relationships of trust and credibility, facilitating ''the process of public acceptance and mobilization'' (p. 6). Useful to these efforts would be development of ''stakeholder network maps that describe the key groups and their positions on fuels reduction, their resources and methods of operation, and potential linkages and partners'' (p. 30).

There are a variety of wildfire education and outreach programs created by organizations and agencies concerned about wildfire problems. Smalley (2003, p. 9), for example, described the ''Firewise'' education program – an outreach program under the auspices of the National Wildland/Urban Interface Fire Program – that ''was designed to educate homeowners, community leaders, planners, developers, and others about the hazards associated with fire'' in their communities. That program focuses on planning, landscaping, home construction, and hazard perception and recognition – issues that are aimed primarily at the individual level of response and mitigation. As noted in other studies, though, the significance of communication linkages to fire management and community well-being suggests that leaders, residents, and managers should also develop skills and capabilities in communicative approaches and capacity-building through strengthening social networks of community. The most successful wildfire education programs are likely going to be those that apply both a broad array of communication strategies and channels, and an inclusive definition of community, as part of their agenda.

DISCUSSION

The intent of this paper was to evaluate the research work on community as that concept is studied in wildfire contexts and as it is addressed in practical applications of fire management. The analysis reveals five trends in current approaches to the topic. First, in wildfire research, ''community'' tends to be defined geographically; there is relatively little discussion of social processes of community as a basis for research into wildfire preparedness, experience, or recovery. Second, much of the research and applied work remains focused on individuals and their experiences, with an emphasis on people's perceptions and attitudes of wildfire risk and blame, and their levels of knowledge about wildfire problems. Third, case studies predominate in the research literature, rather than an integrative body of work or findings. Fourth, research work tends to be highly applied and to exhibit a problem solving, technical focus. Finally, though there has been considerable, recent use of the concepts of "social networks," "social capital," and "civic participation," in scholarly writing about wildfires, there are very few studies that actually operationalize and measure these social qualities, or attempt to gauge their influence in managing wildfire problems.

Certainly traditional types of social and social-psychological research should not be forsaken in studying wildfire and community relationships – but there may be new insights to be gained by applying new theoretical and methodological approaches to problems in the intersection of wildfires and communities. For example, the literature about health effects of wildfires and other disasters is instructive not only for its analyses of individuals directly suffering wildfire effects (smoke inhalation, injuries and related disorders, burns, work related injuries, and so on), but also because this literature often places personal health effects in social contexts. Emergency department and hospital "cases" are not only individuals suffering a physical or emotional medical crisis – they are also people who have families and jobs, and who may need to access medical and social services as a result of their traumas. Moreover, some people are more likely than others to experience the negative public health impacts of wildfires, including firefighters themselves (smoke inhalation, burns, and physical injuries), and persons with asthma or lung disease who are affected by the fine particulates in wood fire smoke (Shusterman, Kaplan, & Canabarro, 1993; Greenough et al., 2001; Norris, 2005).

Another fruitful area of research may be that of gender issues in disaster (O'Brien & Atchison, 1998). Enarson and Morrow (1998, p. xii) explain that, "Traditional paradigms in disaster studies have, for the most part, left women's lives largely unexamined," though disaster typically occurs on "gendered terrain." The authors suggest (p. 4) that, "The social experience of disaster affirms, reflects, disrupts, and otherwise engages gendered social relationships, practices, and institutions … . Disaster management is correspondingly engendered … ." Studies of gender relations and gender differences are beginning to emerge in the broader scholarly literatures of natural disasters, though sometimes researchers will subsume these topics under more general concerns with "family" response to fire and other disasters. The roles of gender, residential longevity, educational levels, social status, and the activities of formal and informal organizations (churches, schools, local voluntary organizations, non-profits, fraternal societies, sports clubs, and so on) are topics that deserve greater attention from researchers. Developing a body of scholarly work around concepts rather than simply cases will advance our understanding of community aspects of wildfires more fully.

An example of a gendered approach to studying community impacts of wildfires is offered by Susanna Hoffman (1998), an anthropologist and victim of the Oakland Firestorm in 1991 (she lost her home and possessions). That fire destroyed over 3,800 home and apartments, and left over 6,000 people homeless (this event is discussed further in Chapter 11 of this volume by Radke). Discussing gender differences across victims in the aftermath of that fire, Hoffman noted that gender roles became more traditional in the days after the fire, with men continuing their functions in the public sphere of life (government, business, and other roles external to the local family or community), while women began to restore functions in the private sphere of life (home, taking care of children and family, replacing possessions). Hoffman hypothesized that men seemed to recover more quickly from the fire events, while women, "uprooted from or severely diminished in their venues, suffered more depression and longer recovery" (p. 58). Friendships were also tested and lost, as friends who had not experienced the devastation found it difficult to cope with the needs of survivors; the extended ties of kinship provided the most reliable assistance, but it fell to the women to facilitate these relationships. A form of coping that provided a more productive return to community well-being was the rise of formal and informal women's support and issue groups. Hoffman (p. 61) observed that the women's groups "pushed for events and processes that reinforced community and provided a sense of achievement over time. And, it was largely women who tatted back neighborhoods like so much lace."

Beyond gender and the social contexts of wildfire health effects, the trend towards rising interest in such concepts as social networks and social capital offers considerable potential for helping to guide future research about community processes in wildfire preparation, effects, and management. Over the past two decades, the notion of "social networks" has provided a provocative conceptual idea for scholars (Stokowski, 1994, 2004), but research studies specific to measuring interactional and structural criteria of social networks relationships have lagged. The emergence of the related concept of "social capital" – defined as "investment in social relations with expected returns" (Lin, Cook, & Burt, 2001, p. 6) – has inspired new interest in analyses of social networks, because network characteristics have been used as measures of social capital.

Some specific social networks issues may prove to be highly relevant for research about community processes and wildfire management. For example, do communities in wildfire areas that have more dense and extensive networks of active social ties (what Freudenburg (1986) referred to as the "density of acquaintanceship") have greater adherence to norms of property clean-up and care-taking? Do these types of communities see greater levels of citizen participation in wildfire education and safety programs? Do such communities develop a shared ethic of place, activate more informal helping mechanisms during wildfire emergencies, or develop stronger formal linkages cross many local and extra-local organizations and agencies – linkages that provide more extensive resources in times of need? To what extent is social capital strengthened through shared disaster-related experiences? To what extent can researchers learn from the experiences of interest-based communities (firefighters, emergency personnel, recovery workers, people involved and connected in neighborhood associations, and so on) about social support and disaster resiliency?

Additionally, the study of social networks in communities facing wildfire dangers might be developed by studying the shared languages and discourses of community well-being and connectedness (Millar & Heath, 2004). Story-telling about prior personal experiences with wildfires and about collective memories of past fires are ways that people informally build social network relationships – ties that may have future applications on other contexts of community. Newcomers to a community are often brought into the shared experiences of community through the myths, narratives, and public history of a place; how do these relationships develop in communities facing wildfire dangers? Does experience with local wildfires lead to increased neighboring activity, development of social ties of community generally, and capacity building through strengthening community social connections? Moreover, how persistent and long-lasting are the social network ties developed from wildfire experiences? And, do such weak and strong connections made in this context have application in other spheres of social and community life?

Finally, analyses of the parallels across various kinds of disaster studies may offer new avenues for researching the social contexts and effects of wildfires. Analyses of a variety of affected groups of people across society, at different levels of wildfire risk and threat, and with different responder, communication, and mitigation strategies, all at different stages of wildfire response (anticipation, experience, coping, mitigating, and remembering), may ultimately produce a richer understanding of the community aspects of wildfire events.

REFERENCES

Brooks, J. J., Brenkert, H., Serby, J. E., Champ, J. G., Simons, T., & Williams, D. R. (2006). Integrating social science into forestry in the wildland/urban interface. *Fire Management Today*, *66*, 35–43.

Brooks, J. J., Champ, J. G., & Williams, D. R. (2004). *Toward understanding public–professional communication about wildland fire and fuels management in Colorado's front range*. Fiscal Year 2003 Progress Report. USDA Forest Service, Rocky Mountain Research Station, Fort Collins. http://www.fs.fed.us/rm/value/brooksj.html.

Burns, S., Sperry, C., & Hodgson, R. (2003). People and fire in western Colorado: Methods of engaging stakeholders. In: P. N. Omi & L. N. Joyce (Eds), *Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings*, April 2002, USDA Forest Service, Rocky Mountain Research Station. RMRS-P-29 (pp. 213–224).

Carroll, M. S., Cohn, P. N., Seesholtz, D. N., & Higgins, L. L. (2005). Fire as a galvanizing and fragmenting influence on communities: The case of the Rodeo-Chediski fire. *Society and Natural Resources*, *18*, 301–320.

Cortner, H. J., & Field, D. R. (2004). Introduction. Humans, fire, and forests: The reemergence of research on human dimensions. *Society and Natural Resources*, *17*, 473–475.

Cox, H. (1998). Women in bushfire territory. In: E. Enarson & B. H. Morrow (Eds), *The gendered terrain of disaster: Through women's eyes* (pp. 133–142). Westport, CN: Praeger.

Enarson, E., & Morrow, B. H. (1998). *The gendered terrain of disaster: Through women's eyes*. Westport, CN: Praeger.

Field, D. R., & Jensen, D. A. (2005). Humans, fire, and forests: Expanding the domain of wildfire research. *Society and Natural Resources*, *18*, 355–362.

Freudenburg, W. R. (1986). The density of acquaintanceship: An overlooked variable in community research? *American Journal of Sociology*, *92*, 27–63.

Greenough, G., McGeehin, M., Bernard, S. M., Trtanj, J., Riad, J., & Engelberg, D. (2001). The potential impacts of climate variability and change on health impacts of extreme weather events in the United States. *Environmental Health Perspectives, 109*(Suppl. 2). Accessed October 4, 2006 from http://ehpnet1.niehs.nih.gov/docs/2001/suppl-2/191-198greenough/abstract.html.

Halvorson, S. J. (2002). *The fires of 2000: Community response and recovery in the Bitter Root Valley, Western Montana*. Quick Response Report no. 151. Natural Hazards Research and Applications Information Center, University of Colorado, Boulder, CO.

Hoffman, S. M. (1998). Eve and Adam among the embers: Gender patterns after the Oakland Berkeley firestorm. In: E. Enarson & B. H. Morrow (Eds), *The gendered terrain of disaster: Through women's eyes* (pp. 55–61). Westport, CT: Praeger.

Jakes, P. J., Nelson, K., Lang, E., Monroe, M., Agrawal, S., Kruger, L., & Sturtevant, V. (2003). A model for improving community preparedness for wildfire. In: P. J. Jakes (Compiler) *Homeowners, Communities, and Wildfire: Science Findings from the National Fire Plan. Proceedings from the 9th International Symposium on Society and Resource Management*, June 2002, Bloomington, IN. (pp. 4–9). http://www.ncrs.fs.fed.us/pubs/gtr/gtr_nc231.pdf.

Kneeshaw, K., Vaske, J. J., Bright, A. D., & Absher, J. D. (2004). Situational influences of acceptable wildland fire management actions. *Society and Natural Resources*, *17*, 477–489.

Kumagai, Y., Bliss, J. C., Daniels, S. E., & Carroll, M. S. (2004). Research on causal attribution of wildfire: An exploratory multiple-methods approach. *Society and Natural Resources*, *17*, 113–127.

Lin, N., Cook, K., & Burt, R. S. (2001). *Social capital: Theory and research*. New York, NY: Aldine de Gruyter.

Lynn, K., & Hill, A. (2006). *Strengthening resilience of rural communities to wildfire in the Pacific Northwest*. Quick Response Report, Natural Hazards Center, University of Colorado, Boulder, CO. Number 185. March. http://www.colorado.edu/hazards/qr/qr185/qr185.html.

Lyon, L. (1987). *The community in urban society*. Chicago, IL: The Dorsey Press.

Machlis, G. E., Kaplan, A. B., Tuler, S. P., Bagby, K. A., & McKendry, J. E. (2002). *Burning questions: A social science research plan for federal wildland fire management*. Report. Moscow, ID: Idaho Forest, Wildlife, and Range Experiment Station.

Millar, D. P., & Heath, R. L. (Eds) (2004). *Responding to crisis: A rhetorical approach to crisis communication*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Norris, F. H. (2005). Range, magnitude, and duration of the effects of disasters on mental health: Review update 2005. Retrieved October 4, 2006 from: http://www.redmh.org/research/general/effects.html.

O'Brien, P. W., & Atchison, P. (1998). Gender differentiation and aftershock warning response. In: Enarson & Morrow (Eds), *The gendered terrain of disaster: Through women's eyes* (pp. 173–180). Westport, CN: Praeger.

Pacific Southwest Research Station, USDA Forest Service. (2004). Rapid response research on fire communication with wildland interface communities. *Recreation Research Update*, No. 50. October.

Sellers, S. (2004). The Southern California fire siege. *Natural Hazards Observer*, *29*(September), 11–12.

Shusterman, D., Kaplan, J. Z., & Canabarro, C. (1993). Immediate health effects of an urban wildfire. *Western Journal of Medicine*, *158*, 133–138.

Smalley, J. (2003). Empowering communities in the wildland/urban interface. *Natural Hazards Observer*, *28*, 9–10.

Steelman, T. A., & Kunkel, G. F. (2004). Effective community responses to wildfire threats: Lessons from New Mexico. *Society and Natural Resources*, *17*, 679–699.

Stokowski, P. A. (1994). *Leisure in society: A network structural perspective*. London: Mansell.

Stokowski, P. A. (2004). Social networks research in resource management: A retrospective, and an agenda for the future. Paper presented at the International Symposium on Society and Resource Management, Keystone, CO. June.

Taylor, J. G., Gillette, S. C., Hodgson, R. W., & Downing, J. L. (2005). *Communicating with wildland interface communities during wildfire*. Open-file Report 2005-1061. Reston, VA: US Geological Survey, USDI. www.usgs.gov/pubprod.

Vogt, C., & Nelson, C. (2004). Recreation and fire in the wildland-urban interface: A study of year-round and seasonal homeowners in residential areas nearby three National Forests – San Bernardino National Forest, California; Grand Mesa, Uncompahgre and Gunnison, Colorado; and Apalachicola National Forest, Florida. *Management Report*, prepared for the USDA Forest Service, Pacific Southwest Research Station, Riverside, CA. March.

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PART IV:
MANAGEMENT AND ECOLOGY

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CHAPTER 11

MODELING FIRE IN THE WILDLAND–URBAN INTERFACE: DIRECTIONS FOR PLANNING

John Radke

ABSTRACT

This paper describes the application of, enhancements to, and use of surface fire spread models in predicting and mitigating fire risk in the Wildland–Urban Interface (WUI). Research and fire management strategies undertaken in the East Bay Hill region (containing the 1991 Tunnel Fire) of the San Francisco Bay area over the past decade are reported. We ascertain that surface fire spread modeling has impacted policy and decision making, resulting in a regional strategic plan where large landowners and public agencies are able to implement fire mitigation practices. Although these practices involve extensive fuel management within a buffer zone between the wildland and residential properties, the residential property owners are still at risk, as no strategy within neighborhoods can be accurately mapped using the current scale of the data and models. WUI fires are eventually extinguished by fire fighters on the ground, up close, and at the backyard scale. We argue that large-scale (backyard scale) mapping and modeling of surface fire spread is necessary to engage the individual homeowner in a fuels management strategy. We describe our ongoing research and strategies, and suggest goals for

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future research and development in the area of large-scale WUI fire modeling and management.

INTRODUCTION

Fire is a natural element of the Mediterranean landscape[1] of California. Some argue that the current practice of fire suppression in this environment may be a misguided effort in land management strategies (Russell & McBride, 2003). While this is likely true for the wildland regions, on the urban fringe, where people live, the practice of fire suppression is regarded as sound policy. However, this practice of fire suppression often results in an accumulation of fire fuels, which leads to the even greater risk of catastrophic fires commonly referred to as *firestorms*.[2] Fire suppression policies must be coupled with fuel management strategies to reduce the probability of such firestorms in the wildland–urban interface (WUI). In this zone where a variety of natural and exotic species intermix with human built structures to form a complex heterogeneous environment, fuel management must be supported by effective fire spread models fueled by accurate and appropriate scale data. Only then can effective WUI fire policy be drafted, plans implemented, and firestorms avoided. This paper describes our efforts to build and fuel fire models at an appropriate scale for the WUI.

Wildland–urban interface fires are extremely difficult to fight. Unlike their wildland counterparts, they can cause extensive damage to both natural and human built landscapes in hours rather than days. For instance, the 1991 Oakland Tunnel fire destroyed 760 homes in the first hour and when it was eventually extinguished late in the day it had destroyed more than 2,700 structures, cost over a billion dollars, and taken 25 lives (Pagni, 1993; Radke, 1995). Even in areas where the "the fire department is vastly experienced and effective at fighting interface fires" (Granito, 2003), catastrophic losses still occur; a 1993 fire in Los Angeles County took 2,600 firefighters, 215 tankers, and 22 aircraft to minimize the loss at 155 homes and 40 other structures. The 2000 Bitterroot Valley, Montana interface fire claimed 72 homes (Granito, 2003) and the 2000 Los Alamos fire destroyed more than 220 structures, left 400 families homeless and was the beginning of the record-breaking wildfire season where 93,000 wildland fires burned close to 7.4 million acres (Hartzell, 2001). Two years later the many WUI fires of southern California would break that record in homes destroyed and overall costs (Rey, 2003).

While WUI fires are on the increase, the State of California is experiencing an unprecedented growth in population and it is predicted that 4.3 million new housing units will be built by the year 2020 (CCSCE, 1999). Of this new development only 20% will likely infill in existing urban areas with the rest expanding the urban fringe (Zhang, 2001). The residents of this expanding WUI often find themselves in a foreign landscape where their inexperience with what can easily become a disaster often leads to them unknowingly becoming catalysts to fire storms (Granito, 2003). The WUI fire problem is becoming progressively worse (US General Accounting Office, 1999, 2002) and to effectively mitigate firestorm conditions, a sound fuel management plan is needed for these regions (USDA, 2000). The vast and diverse landscape of California insures this task will be difficult.

Fire models that are now popular in fighting and mitigating wildland fire will play a key role in the methods employed to formulate a WUI fuel management plan. The California Department of Forestry (CDF) has mapped and modeled fuels at a state wide scale in order to predict high risk regions and better allocate fire fighting resources (CBF, 2000). Modeling fire can lead to more accurate predictions to better fuel management prescriptions. These advancements can lead to sound land management planning, which in turn can produce change and a safer environment. The key to most fire models has been the identification of the fuels, their distribution on the landscape, and the weather conditions during the fire event. Although popular fire models, calibrated under wildland fire conditions, have proved valuable in wildland regions (Finney, 1998; Finney, McHugh, & Grenfell, 2005), there is growing doubt about their applicability to the WUI. Much of this doubt is based on the contrast of fuels between the two regions. Vegetation in the wildlands, where natural processes of succession and invasion apply, tends to be homogeneous. The WUI, dominated by humans with a variety of landscape tastes, is a heterogeneous patchwork of vegetative and structural fuels (Radke, 1995; Cova, 2005). The direct application of wildland fire models in the WUI will not likely lead to accurate and predictive results. New fire models (Cohen, Rigolot, & Valette, 2004) and data gathering techniques are needed if we are to predict fire spread and be successful at avoiding firestorms in the WUI.

FIRE SPREAD MODELS

Although fire spread models have been well documented (e.g., Scott & Burgan, 2004, 2005; McKenzie, Peterson, & Alvarado, 1996; McKenzie, Prichard, Hessl, & Peterson, 2004), it is prudent to briefly review their origins and development here. Early wildland fire models such as the *McArthur meters model* widely used in eastern Australia (McArthur, 1966, 1967), and the *Rothermel model* used in the United States as part of the US Forest Service's BEHAVE system of fire prediction (Rothermel, 1972; Burgan & Rothermel, 1984), were based on the assumption that radiation is the primary mode of fire spread. During a wildland fire, rapidly heated vegetation undergoes pyrolysis, decomposes emitting flammable gases, mixes with oxygen, and combusts. This combustion adds to the radiation, which in turn impacts combustion, and so the fire spreads. It is not surprising that the physically based, deterministic fire growth models are all built employing these principles. These wildland fire growth models: BEHAVE (Andrews, 1986), Farsite (Finney, 1998), Wildfire (Todd, 1999), Prometheus (CIFFC, 2004), and Fire Star (Cohen, Etienne, & Rigolot, 2002), simulate fire spread across landscapes composed of heterogeneous fuels on varied topography during specific weather events.

Rothermel's work revealed that fuel chemistry varies from plant species to plant species, impacts pyrolysis, causes some fuels to combust before others, and adds to the complexity of the fuel variable in fire model. In addition, this model included fuel moisture and external or physical properties such as surface area to volume ratio, to classify the fuel properties of vegetation. This resulted in the development of a number of fuel types characterized by moisture content, size, shape, quantity, and both horizontal and vertical spatial arrangement of vegetation over the landscape. These fuel types are now common inputs to the wildland fire growth models (Scott & Burgan, 2004) and are all typically derived from the original National Forest Fire Laboratory (NFFL) fuel models (Anderson, 1982).

Topography, a second variable of the wildland fire models, can influence the type and growth of vegetation as well as the spread of fire during an event. Fuels are impacted by: steepness of slope, exposure to sunlight and prevailing winds, amount of precipitation, and the drainage of soils (Alexander, Seavy, Ralph, & Hogoboom, 2006; Rollins, Morgan, & Swetnam, 2002). Besides the long-term impact on the growth of fuels, topography can become a catalyst during a fire by channeling winds up slope, causing a chimney effect, and prematurely lowering the fuel moisture content, thus accelerating combustion. In addition, winds fanning fire moving downhill from the crest can assist spotting with burning airborne materials (Taylor & Skinner, 2003). Even if it only serves to accommodate heavier burning debris to roll downhill, topography is an important ingredient to the spread of fire.

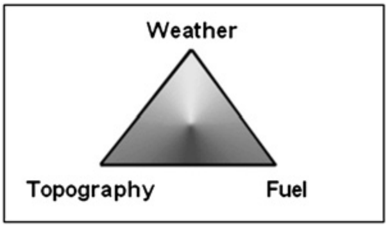

Fig. 1. Fire Triangle.

Weather is the final variable in the spread of wildfires. Wind, temperature, and humidity all factor into the equation (Alexander & De Groot, 1988; Goens & Andrews, 1998). Strong winds not only offer a good source of oxygen, they also serve to dry out the fuels in their path, push flames into new fuel sources, and can transport light burning debris downwind, igniting small spot fires (Randall, 2003). Video from the 1991 Oakland Tunnel fire provided evidence that WUI fires can generate their own winds, creating a firestorm. The air mass directly above the flames is superheated and rises, creating a vacuum at ground level that sucks in a fresh supply of oxygen from the fire's periphery. This continuous process can result in a tornado like effect, fanning winds, causing temperatures to rise, and intensifying combustion (Goens, 1992). The resulting firestorm can destroy everything in its path and be extremely difficult to control and extinguish.

Fuel, topography, and weather constitute the basic ingredients of the popular fire spread models as they impact the timing of and gases released through pyrolysis. It is important to measure these three phenomena, commonly illustrated as a triangle (Fig. 1), symbolically following the traditional fire triangle composed of oxygen, heat, and fuel (Brown, Dayton, Nimlos, & Daily, 2001; Rothermel & Rinehart, 1983; Beer, 1990).

MODELING RESIDENTIAL AND WILDLAND FIRE HAZARD: EAST BAY HILL CASE STUDY

The hills east of San Francisco Bay contain the right conditions for a *firestorm*. They are dominated by rugged topography, a shifting WUI, a Mediterranean climate, and a recent management practice of fire suppression. The 1991 Tunnel Fire was a wakeup call for a proactive approach as the traditional reactive response strategy of spending resources once the fire had begun had failed. Continued urban sprawl into the peripheral regions demanded a comprehensive fire response strategy, a preemptive strike, and a policy and management shift to practicing prevention to avoid a similar event in the future.

Following the 1991 Tunnel Fire, our research group at the University of California, Berkeley undertook the first fire spread modeling in the WUI region of the East Bay Hills (Radke, 1995). Our mission, to spatially enable a fire model by embedding it in a Geographic Information System (GIS), produced a Spatial Decision Support System (SDSS) that predicted high risk fire regions and supported fuel management and mitigation efforts by the local Vegetation Management Consortium. After a survey of the wildland fire models of that period, we chose to embed the *Rothermel* based BEHAVE system of fire prediction (Rothermel, 1972; Burgan & Rothermel, 1984).

Spatially Enabling Fire Models (circa 1995): Oh BEHAVE

In 1995, the *Rothermel* based BEHAVE system of fire prediction (Rothermel, 1972; Burgan & Rothermel, 1984) was a cell-based spatially static model[3] that could not map or describe what the regional fire risk of an area was. To enhance this model, we spatially enabled it by embedding it into a GIS where the final plotted results mapped cumulative potential fire risk over the region. Using common GIS tools[4] to classify BEHAVE predicted risks, we were able to identify contiguous areas of high, medium, and low fire risk.

Applying the BEHAVE model to the heterogeneous WUI raised two important issues: (1) the resolution or scale of the data and subsequent modeling would have to increase from the traditional wildland applications scale (1:50,000 or smaller); and, (2) the urban residential region containing built structures would force a modification to the traditional wildland fuel inputs of the model that account for only natural landscape fuel. Fig. 2 maps our data gathering, processing and modeling effort, illustrating our two path approach to fire prediction.

Although the USGS Digital Elevation Model (DEM) data were the standard dataset used to calculate slope for wildland fire models, the heterogeneous nature of the WUI forced us to increase the scale and accuracy of our surface model. By the mid 1990s advances in data collection and computer processing, along with national programs for data archiving and dissemination, made it possible to obtain and accurately model the *topography* of the East Bay Hills within a GIS. We combined USGS digital

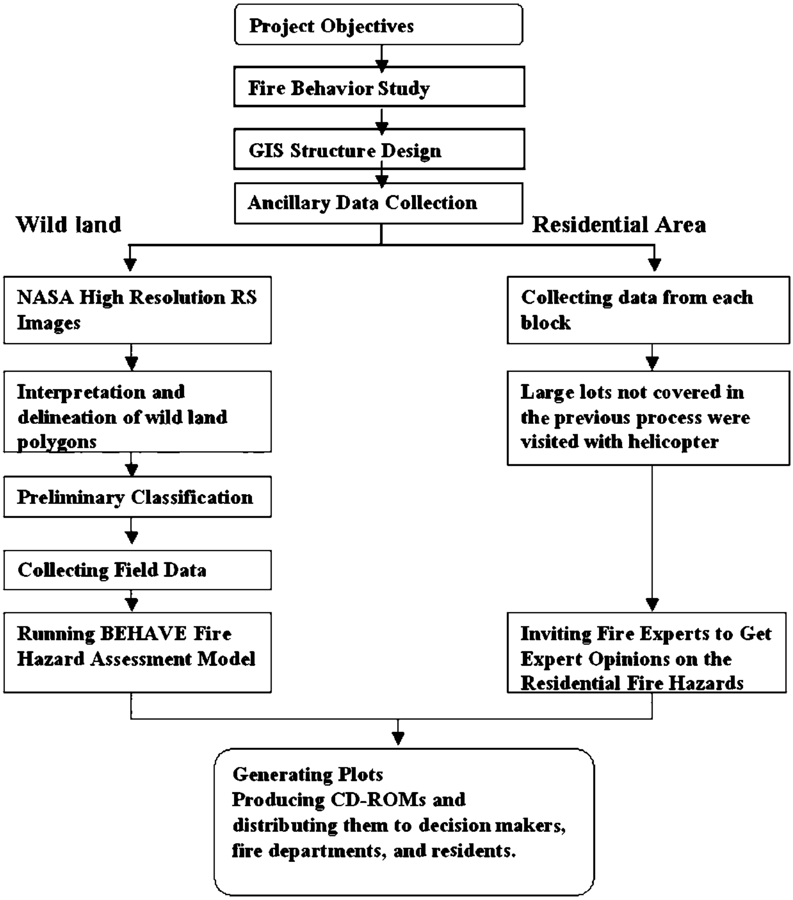

Fig. 2. Data Flow and Modeling for the WUI.

hypsography, hydrology, and DEM data from the 7.5 min USGS quad series (1:24,000 scale data) to build a digital terrain model represented as a Triangulated Irregular Network (TIN). From this TIN we were able to calculate accurate aspect and slope datasets to complete the topographic input for our fire models.

Regional weather stations made it possible to measure and interpolate weather conditions during real fire events to also satisfy the *weather* requirement for our fire models. Although five historic fires had burned a cumulative 1,200 acres, during onshore winds from San Francisco Bay, the

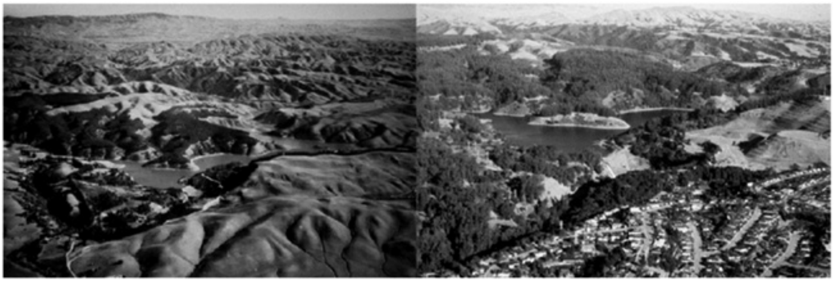

Fig. 3. Lake Chabot Region 1920s and 1990s.

catastrophic winds are the offshore winds from the east. Known as the Diablo winds, with velocities in excess of 20 miles per hour, temperatures in excess of 80 degrees Fahrenheit and measured humidity of less than 20%, these are the winds that fuel firestorms and were used to parameterize our fire models.

Unlike typical wildland regions, *fuels* in the WUI are complex and include both vegetation and human built structures. The East Bay Hill landscape had transformed from a predominantly grassland in the 1920s to one that has fringe forests dominated by volatile eucalyptus (*Eucalyptus globulus*) and Monterey pines (*Pinus radiata*) today. Grassland, planted exotic garden vegetation, winding narrow roads, and residential structures of various sizes and construction materials all add to the heterogeneous nature of the WUI. Fig. 3 illustrates the vegetative evolution of the Lake Chabot region from the 1920s to 1990s and serves as an excellent example of conditions necessary for a catastrophic fire.

These complex conditions forced us to alter the scale and process for gathering data on fuels in the WUI. Rather than employing Landsat imagery (30 m^2 resolution) which is often the case in wildland vegetation assessment, or the standard aerial photos used in the production of the USGS 7.5 min quad series, we used imagery from the NS001 sensor aboard a NASA aircraft on a low altitude mission (7 m^2 resolution) and hi-resolution aerial photos from the same mission to better map the smaller clusters of common-type fuels. Fig. 4 is an infrared image from this sensor of a small area on the edge of the 1991 fire. In the wildland region, homogeneous patches of vegetation were registered, digitized, and then visited in the field for identification and classification.

In the residential areas of the WUI, the combination and variety of vegetation and structures made it impossible to define and classify polygons

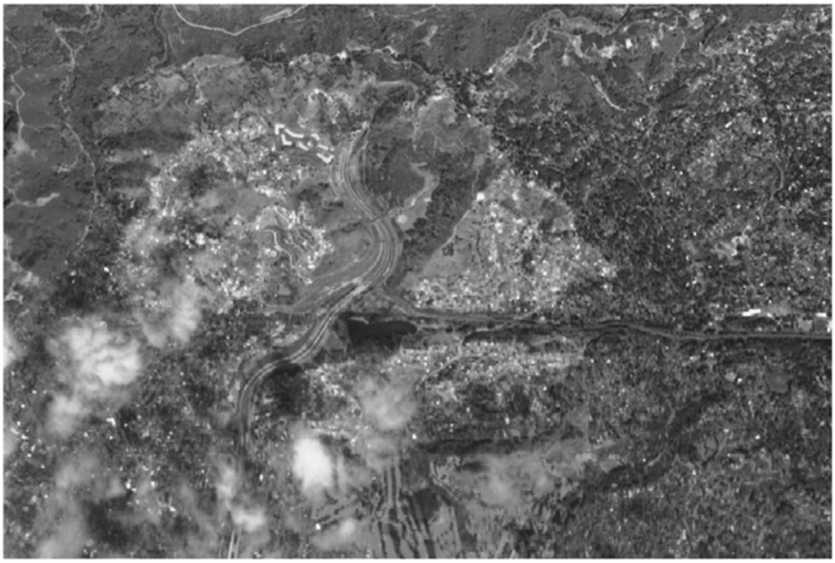

Fig. 4. An Infrared Image Over the 1991 Tunnel Fire Area.

based on a single fuel condition. Here we made observations at point locations distributed throughout the study site and later classified the various fuel conditions into data layers. The conditions observed were not based on an individual property or structure, but on the characteristics of a neighborhood. The same observer evaluated groups of structures to establish the sample neighborhood of similar attributes. Observations were taken at regular intervals and adjusted when one or more of the eight fuel characteristics being monitored and changed. The 3,200 plus observations were spatially decomposed into a set of Voronoi polygons and each fuel characteristic being monitored was represented as one of eight mapped layers.

The data inputs from the wildland region were run through the BEHAVE model and mapped. However, the urban areas of the WUI produced a new variety of fuels and fuel conditions that had never been calibrated in a mathematically derived fire model such as BEHAVE. Here we proposed a new model: a residential fire hazard assessment model (RFHAM), based on knowledge from fire experts and a set of rules formulated to select criteria for fuel assessment and fire risk prediction. From observations while fighting the 1991 Tunnel Fire, fire hazard conditions in the WUI were divided into two classes: (1) vegetation type and its distribution with respect to structures; and (2) structural materials and building design. Expert knowledge from fire fighters was used to create the WUI data dictionary (Table 1) and fuel the RFHAM. Fig. 5 maps the combined results from the two spatially enabled fire models mapping ordinal hazardous conditions.

Our results showed that almost fives times the area burned by the 1991 Tunnel Fire, over 7,600 acres or 47% of the residential region in the hill area, was in high hazardous vegetation conditions. In addition, over 5,500 acres or 35% of the residential region was considered high hazard with regard to structural fuels such as wood shingled roofs and overhanging wooden decks.

POLICY IMPLICATIONS

Now that the areas most prone to a WUI firestorm were identified and mapped, the East Bay Vegetation Management Consortium (EBVMC), a group formed by nine local cities and agencies that manage public lands and regulate private lands in the East Bay Hills (Acosta, 1994), began a long process of setting policy, developing a strategic plan, and implementing a fuels management program. This EBVMC is part of a larger network of groups that address fire issues in the hills and includes: the Hills Emergency Forum (HEF) made up of city managers and CEOs of seven cities and special districts, and the East Bay Hills Fire Chiefs' Consortium (EBH FCC) made up of 16 Fire Chiefs in the region (Fig. 6).

With the existing conditions and potential hazards in both the residential and wildlands identified, the EBVMC undertook a yearlong process of developing a plan that would recommend appropriate mitigation measures for hazard reduction and establish standards for a regional approach to vegetation management. Input to the plan came from a Technical Advisory Committee, a Citizens Advisory Committee, the general public, and local homeowner associations. A draft plan (*1995 Fire Hazard Mitigation Program & Fuel Management Plan*) was forged and comments sought at a number of public presentations.

The plan identified hazard reduction programs targeting three critical factors involved in WUI fires: ignition, fire spread and behavior, and "values at risk" or vulnerable receptors such as houses and adjacent landscapes. Using direct output from our GIS based fire risk model, the plan recommended several strategies to establish a network of fuel modification zones and fuel breaks that would provide a protective buffer zone between the developed urban areas and adjacent wildlands (Kent, 2005 Press. Comm.).

Table 1. Fire Fighter Knowledge Derived Structural Data Dictionary (From Radke, 1995).

	Fuel Characteristics	Measurement	Low	Moderate	High	Extreme
Structural Fuels	Combustible roof materials	% structures with wood roofs	None	< 0%	20–50%	> 50%
	Siding, decking, and fencing	% structures with combustible siding, decking, or fencing	None visible	< 20%	20–50%	> 50%
Vegetation Fuels	Surface fuel density	% surface area supporting combustible surface fuels	< 20%	20–50%	50–70%	> 70%
	Aerial fuel density	% surface area covered by tree canopy	0–10%	10–30%	30–70%	> 70%
	Vertical continuity	Presence of ladder fuels and crown fires potential	None	Isolated ladder fuels individual trees to crown	Widespread ladder fuels Stand-wide crown fire expected	
	Tree height	Tree height	Short = < 50 ft	Intermediate = 50–90 ft	Tall = > 90 ft	
	Flammability	Overall flammability of fuels	Irrigated grass, ornamental hardwoods	Cured grasses native hardwoods Cultivated landscapes	Pyrophytes (Juniper, pine, eucalyptus, etc.)	
	Fuel clearance	Clearance distance of combustible material from structure	Poor = < 10 ft	Moderate = 10–30 ft	Good = 30–100 ft	Excellent = > 100 ft

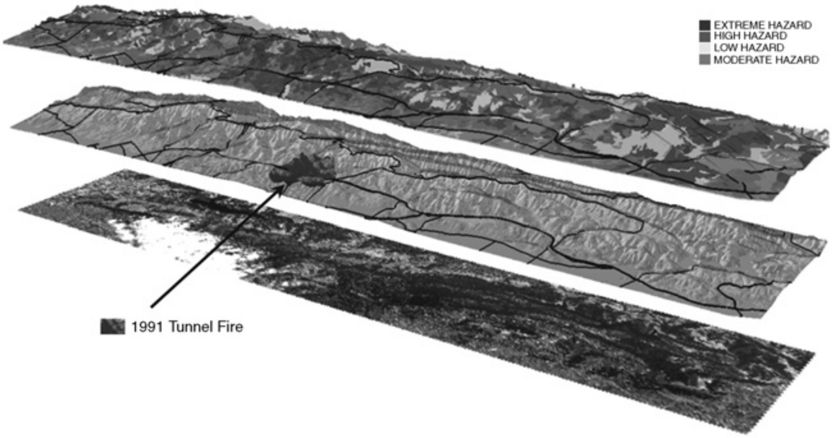

Fig. 5. The Combined Results from the Two Spatially Enabled Fire Models.

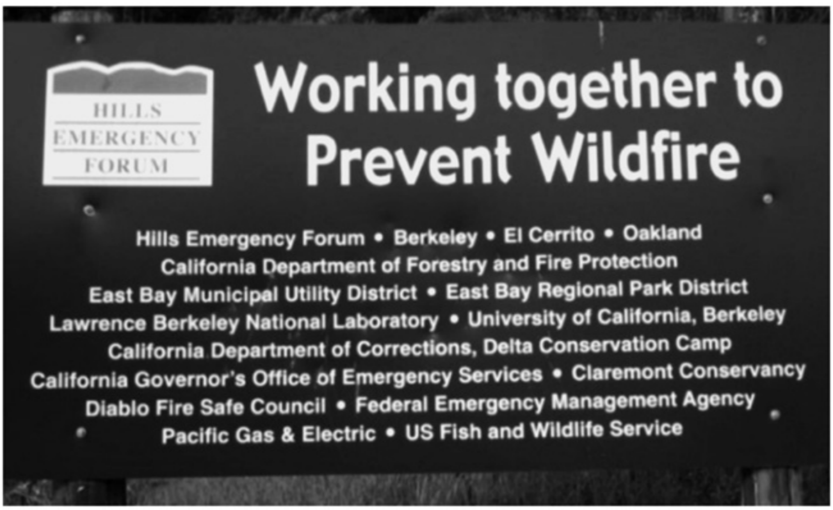

Fig. 6. A Sign Posted Near the Site of the 1991Oakland Tunnel Fire.

These protective buffer zones were identified, mapped, and targeted as vegetation treatment polygons by our WUI fire modeling efforts. They were classified as prime targets for defensible space programs that would create areas of more benign fire behavior, as well as locations from which to attack and potentially control a wildfire. The plan was approved by the East Bay HEF October 1995 and accepted by many of its member agencies the following year.

The East Bay Regional Parks District (EBRPD), one of the largest landowners in the hill area, voted to accept it in October 1996 and approved an implementation process in October 1997 which instructed the General Manager to prepare amendments to hill park Land Use Development Plans (LUDP) and Environmental Impact Reports (EIR) for the California Environmental Quality Act (CEQA) compliance, necessary for implementing new projects. The quantified measurements from our GIS based fire modeling effort were adopted by the EBRPD Fire Hazard Reduction EIR/NEPA Working Group as they developed their wildfire problem statement in 2001 which was eventually adopted December of 2003. The same year the park district teamed with the California Office of Emergency Services (OES) through the FEMA Hazard Mitigation Grant Program under a Presidential Disaster Declaration to implement the vegetation management project and mitigate fire risk on a polygon by polygon basis as identified by our fire modeling research (Kent, 2005). To continue to their long term wildfire protection and plan for the future, the EBRPD successfully put Measure CC on the November 2, 2004 ballot which will provide more than $45 million over the next 15 years for essential maintenance.

Although the HEF mission was building interagency consensus on the development of fire safety standards and codes, and developing fuel reduction strategies, several of its members chose to pool their resources in mitigating initiatives. The University of California, Berkeley joined with its neighbors, Lawrence Berkeley Laboratory (LBL), East Bay Municipal Utilities District (EBMUD), the City of Oakland, and the EBRPD to reduce the fire risk in their region by removing invasive eucalyptus trees (Fig. 7) and decadent brush from ridge top locations (Klatt & Mandel, 2005).

They all agree that ignition cannot be completely eliminated from this region, but by removing large stands of potential firewood from the WUI, they can greatly reduce the risk of repeating the 1991 firestorm.

LESSONS LEARNED

Many large landowners have and continue to remove fuels and improve the hazardous conditions on their lands adjoining the residential neighborhoods in the WUI. Some neighborhoods led by citizen-based non-profit organizations play a significant role in drafting and setting vegetation management

Fig. 7. Removal of Invasive Eucalyptus Trees.

policy. The Claremont Canyon Conservancy formed January 2001 in response to wildfire hazards and "advocates an integrated fire management plan (IFM) where all parties share in the responsibility of creating defensible space to reduce potential damage and to aid firefighters in their role of fire suppression" (Claremont Canyon Conservancy, 2006). However, many neighborhoods in the region remain much the same as they did a decade ago: in high fire hazard zones.

Although a protective buffer zone has been established, the regional scale of our study did not directly map the conditions in an individual's backyard. This leaves the residential property owners at risk in areas with no fire strategy aimed at the neighborhood level. In order to engage the individual homeowner in the process and prescribe property based mitigation technologies, larger scale data and modeling are necessary.

Within the neighborhood is where the WUI fires are eventually extinguished by fire fighters, on the ground, up close, and at the backyard scale. Here driveways, or even sidewalks, are the critical fuel breaks where defensible space between houses and vegetation is measured in feet and houses themselves contribute a huge concentrated amount of fuel. It is clear that WUI fires are neither wildland, nor urban, and fighting them, modeling them, and prescribing mitigation technologies is leading us toward a larger spatial scale of at least 1:2,000. If we are to effectively model WUI fire spread and risk, we need to undertake fuel mapping at the individual property or yard level where an individual tree canopy and house can be mapped. New fire models (Cohen et al., 2004) built specifically for WUI fires require data gathering techniques beyond what we have employed to date.

WUI MODELING: TOWARD A LARGER SCALE

Farsite (Finney, 1998), developed mainly for simulating the spread pattern of wildland fires, is by far the dominant fire spread model in use today. Following the use of Farsite in the WUI region of Claremont Canyon (Kim, 2001), we discovered the model made predictions that were too coarse to be useful and it was not sensitive to the heterogeneity of the region. Firebreaks that might serve as a resource for stopping a fire were simply overrun by several iterations of the model. This appears to be true for all popular wildland fire models and suggests a new WUI model is needed at the property or backyard scale. We are joined in this assertion by Morvan and Dupuy (2001) who found that in the Mediterranean Regions of Europe, in order to more accurately delineate fuel breaks, they had to increase the scale at which they mapped fuels. Parallel to the fire modeling approach we took (Luo, 2004) they modeled fuel distribution at a large and more appropriate fuel break scale by employing cellular automata (CA).

Cellular automata (CA) models can be considered counterparts to the vector based Farsite model. Rather than map fire spread along an elliptical front (like Farsite), they treat space and time as discrete and all interactions are local. The state of any cell depends on the state and configuration of other cells in its neighborhood, which is defined as the immediate adjacent set of eight cells. During fire propagation, cells are ignited one after another contiguously, illustrated in Fig. 8. These model characteristics make CA models ideal for handling the heterogeneity of the WUI and share some similarity with our first spatially enabled BEHAVE model (Radke, 1995).

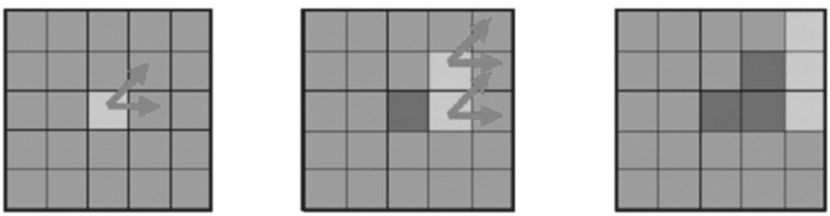

Fig. 8. The Process of Fire Propagation in a Cellular Automata Fire Model (Luo, 2004).

Although several studies have applied CA to fire (Karafyllidis & Thanailakis, 1997; Hargrove, Gardner, Turner, Romme, & Despain, 2000), it was Berjak and Hearne (2002) who added Rothermel's fire physics equations to regulate the fire spread rate and produce a more realistic outcome. However, their model prediction accuracy was tied to the choice of cell size and the predicted rate of spread. If fire spreads quickly and covers one cell size in less than one time step, the fire spread rate is under-estimated. If cells are enlarged to accommodate rapid spread rate, they become weak in accounting for fuel heterogeneity. By modifying this model (Luo, 2004) and allowing multiple iterations in each time step, smaller cell sizes are possible with flexible directional spread.

Modeling the spread of fire in Claremont Canyon using both Farsite and a modified CA model (Luo, 2004) suggests in Fig. 9 that CA models, with their ability to accommodate heterogeneous data and map individual streets as firebreaks, are a promising approach to predicting fire spread in the WUI.

LARGE-SCALE MAPPING IN THE WUI

If a shift to large-scale (approaching 1:2,000) fire model inputs is to be realized, some new technologies must be built. If we consider the three edges of the fire triangle as inputs, moving to a larger scale requires new technologies for both *fuel* and *weather* mapping. Our work to this point suggests the following goals for future research and development in the area of large-scale WUI fire modeling and management (Fig. 10).

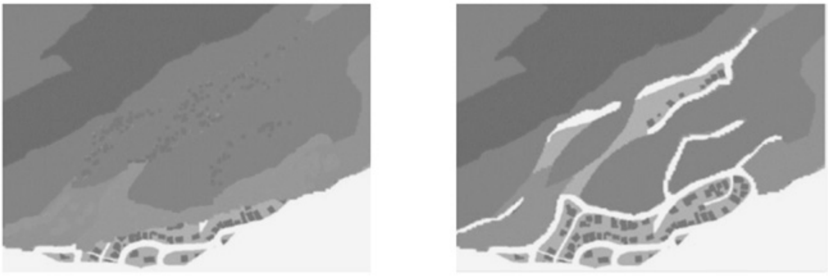

Fig. 9. Comparing the Results from Farsite (left) and Luo's (2004) Cellular Automata Fire Model (right).

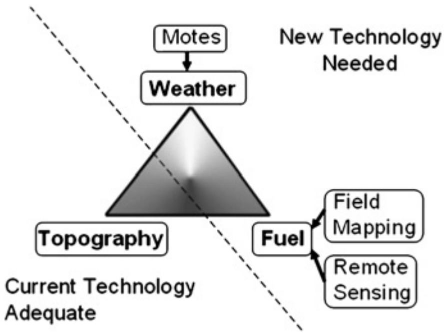

Fig. 10. Large-Scale Fire Research Requires New Technologies for Data Mapping.

MAPPING LARGE-SCALE FUELS

Identification and modeling of fuel regimes in the WUI is complex, boundaries between fuel types are often discrete and extreme, and fuels are constantly changing from year to year. In order to build and execute realistic WUI fire models, a dynamic process for detecting and mapping fuels at a large-scale is needed. In order to make this process practical and useful for mitigation and planning in the many communities experiencing rapid growth, it must be affordable and thus based on easily available data sources. Remote sensing is looked upon as a resource and technology that can deliver under such constraints. It is relatively automatic, cheap per km^2, temporally repetitious of the same region, and able to produce data in near real time. Although spatial resolution or scale was an issue in the 1990s limiting mapping to a regional or neighborhood scale at best, new sub meter resolution satellite sensors such as IKONOS and QuickBird have graduated remote sensing to a scale approaching backyard or property extent.

The greatest challenge to fuel mapping for these new remote sensors lies in image interpretation. With such high spatial resolution data, structural fuels (houses) with asphalt shingles on their roof reflect a similar signature to asphalt driveways and roadways. The houses are intense sources of fuel that assist in the formation of a firestorm, while roads and driveways provide a firebreak. In addition, structures and roadways are often masked by tree canopy over head, rendering them difficult to interpret. The difference between an asphalt base under a tree or shrubs forming a vertical ladder from the ground to the tree canopy, is critical in determining the volatility of fuels as input to a fire model.

Traditional supervised maximum likelihood classifications solely based on spectral properties, do not perform well in a heterogeneous image of the WUI. Hybrid approaches (Kim & Landgrebe, 1991) using morphological filters (Koskinen, Astola, & Neuvo, 1991; Soille & Pesaresi, 2002) that employ set operators to correct object shapes and preserve even the smallest or thinnest objects, appear promising for solving unstable outcomes from spectral classifications. The shape of houses versus the shape of roadways can prove quite valuable during pixel classification. However, in the WUI where overhanging tree canopies mask much of the roadway, misclassified pixels still occur (Luo, 2004) rendering the human image interpreter critical to the process.

To improve interpretation and solve the large-scale fuel classification problems we merge high resolution remotely sensed imagery with ground based yard scale mapping, removing the disadvantages of field survey by enlisting the help of a volunteer public who stand to gain the most from the results of successful WUI fire modeling. This workforce, the homeowner, is the same volunteer group that insures their vegetation-to-structure clearance meets local guidelines. If compliance is not achieved, the local government deploys a crew to do the property and the homeowner is required to pay the cost (Table 2).

Traditional labor intensive, costly, and slow field surveys are replaced with a massively parallel homeowner based observation and reporting system. We avoid the disadvantages of field survey with a simple and efficient

Table 2. Comparative Fuel Survey Approaches.

	Field Surveys	Remote Sensing
Advantage	✓Accurate ✓House and yard scale	• Automatic • Cheap • Fast • Real-time Possible
Disadvantage	✓ Labor Intensive ✓ Costly ✓ Slow	• Less Accurate • Often neighborhood to regional scale

iMap

web based solution to gather, map and maintain a comprehensive database on fuel conditions. We developed a bi-directional (Koskinen et al., 1991) Web based GIS-mapping instrument called ***iMap*** that is based on a new web-mapping component (.dll) included in an ActiveX Web-information platform (.ocx) (Radke, Repetti, & Xu, 2005; Xu & Radke, 2005). This grass-roots technology allows data, such as the latest imagery from a high resolution satellite (0.6 m^2 resolution), to be downloaded from a server through a common Web protocol, interpreted, delineated and documented locally, and uploaded to the server in real time or at some later date. The users of the technology, often homeowners, view high resolution imagery of their property or their neighborhood, identify and draw boundaries around the vegetation and structural fuels, and encode their information into a common database.

The ***iMap*** technology allows data, from the eyes of the community, to be incorporated into the production of the fuels database that is necessary for the shift in scale of the WUI fire modeling effort. Data describing the fuels and used as input to the fire models is greatly enhanced. The ***iMap*** system is currently undergoing testing in Claremont Canyon (Figs. 11 and 12).

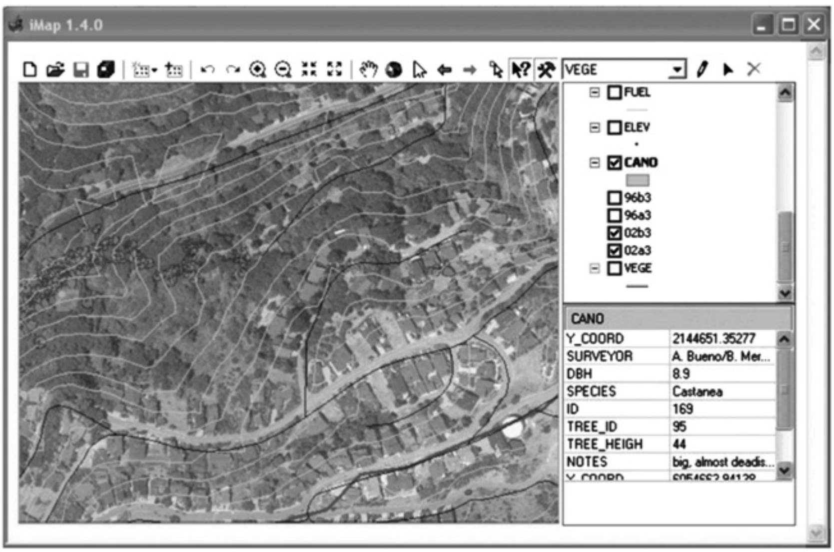

Fig. 11. Graphic User Interface of iMap version 1.4.0.

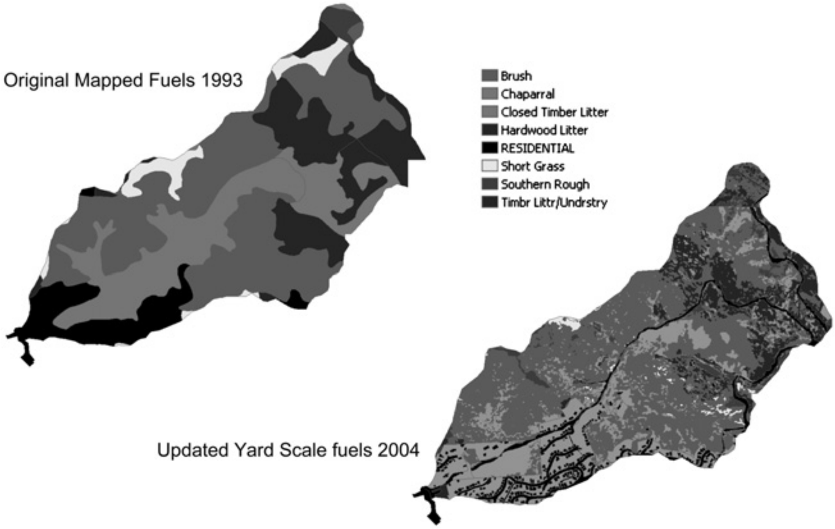

Fig. 12. A Shift from Small to Large-Scale Mapping of Fuels in Claremont Canyon.

MAPPING LARGE-SCALE WEATHER

In 2002 and 2003, the University of California sponsored two wildfire physics workshops to explore the development and use of wildland fire models in predicting event outcomes. At those workshops, Michael Bradley introduced a physics-based computer simulation system running on the Lawrence Livermore National Laboratory's supercomputer that predicted wildfire behavior for specific weather conditions, types of vegetation, and terrain (Bradley, 2002). This atmospheric based approach was the first attempt to model large-scale weather by simulating 10 m resolution data, or the micro weather occurring in the back yard. Bradley's research team correctly pointed out that current fire models not only failed to map important local and often dramatic terrain and vegetation change, they did not account for local weather patterns and rapidly changing winds that determine rate and direction of fire spread. To effectively model WUI fires, high resolution weather data are needed.

With significant advances in Micro-Electro-Mechanical Systems (MEMS) and Nanotechnology (Pister, Kahn, & Boser, 1999; Warneke, Last, Leibowitz, & Pister, 2001; Lawlor, 2005), it is now possible to develop and deploy self-configuring, self-healing, scalable, and dynamic wireless sensor networks from unmanned aerial vehicles (UAVs) (Warneke & Pister, 2002). Moving beyond weather simulations we attempt to gather large-scale or micro weather data for our fire models by deploying portable, wireless weather sensors (motes) ahead of the fire line. With funding from the National Science Foundation (2002, ITR/IM-0121693) we begin to develop and test an adaptive real time mesh sensor network of Global Positioning System (GPS) enabled mote computers based on TinyOS (Culler, Hill, Buonadonna, Szewczyk, & Woo, 2001) and with onboard temperature, pressure and relative humidity sensors. Initial results of sensor testing (Doolin & Sitar, 2005) indicate this approach looks promising for delivering the backyard scale weather data needed for large-scale CA fire modeling.

Although still in its basic research phase, weather sensor motes will either be hand deployed or dropped by an air vehicle, such as a UAV or helicopter, in strategic locations ahead of the fire line. Their drop pattern is critical for configuring a successful network of signals, and a spatial coverage to complete a grid of micro climate sensors for fire model input. Once on the ground the motes begin to wirelessly communicate with one another and employ an adaptive and self-configuration capability to quickly establish a mesh network after which data transfer begins. The GPS chip is activated on each mote and its location is transmitted over the network to a base station where a spatial pattern of mote deployment is calculated, mapped, and transmitted to a web-enabled GIS.

With mote location information in hand, the Incident Commander can assess the coverage and either issues a second deployment to sensor deficient regions or if the pattern of the motes is deemed spatially adequate, orders the activation of the mote-based weather sensors. The weather data streams across the mesh network and eventually fuels the fire model with real time, large-scale data (Fig. 13).

One of the main hazards to these motes is the fire itself and eventually some or all of the first deployment will fail (Fig. 14).

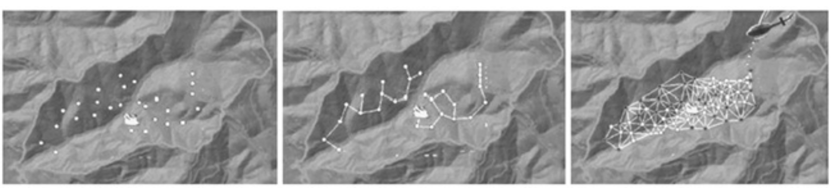

Fig. 13. A Second Deployment of Motes Completes the Mesh Network.

Fig. 14. A Weather Sensor Mote Before and After a Burn.

As the fire spreads and motes fail, a strategic deployment plan is activated where second, third, and more deployment missions are ordered and the mesh network migrates ahead of the fire line. Although our experiments have been oriented to answering basic research questions and mote deployment has been extremely orchestrated, it is likely these miniature mobile weather stations will soon satisfy the large-scale sensing of weather data needs.

MAPPING LARGE-SCALE TOPOGRAPHY

Although it is possible to satisfy our current fire modeling needs with relatively accurate large-scale surface models, new technologies are emerging that offer more information with greater accuracy and less uncertainty. Models now built by combining a DEM with hypsography and hydrology data from archived government sources are slowly being replaced with topographic models born from LIDAR (LIght Detection And Ranging), which uses laser pulses to determine the distance to an object or a surface. When combined on an airborne platform with navigation instruments such as a GPS receiver and an Inertial Measurement Unit (IMU) tracking velocity and attitude, a very high resolution topographic surface model can result.

With this ability to measure the surface of the earth at a very high resolution, houses and even individual tree structures can be realized providing the data necessary to accurately model the built structure of the WUI. Although still in very exploratory stage, this will lead to more sensitive fire modeling and predictions.

Fig. 15. Accountability for Fire Protection at the Backyard Level.

CONCLUSION

While our early neighborhood approach to mapping WUI fire potential was a step in the right direction, our recent research into this significant problem reveals that the heterogeneity of conditions on the WUI, along with the regional scale at which we were addressing the problem was not sufficient. After applying new wildland forest models to the WUI, we discovered they were not effective where heterogeneous fuels of both vegetation and structures dominated the landscape. The models were not sensitive to the many subtle firebreaks that dominate the WUI landscape and act as useful barriers for supporting firefighters' efforts to contain a fire. By shifting to a large-scale (backyard level) fuel modeling scheme, and adopting a CA approach to fire spread modeling, we can better address the heterogeneity issue in the WUI to more accurately identify and map potentially high fire prone areas.

Although fire spread research has come along way in the past decade, the WUI still remains a relatively uncharted region where models and devices such as the ones we introduce here, should prove helpful. Knowledge gained here will help us better prescribe and mitigate, reducing fuels in the WUI and maintaining a safe environment.

Claremont Canyon has been the site of our most recent data gathering, processing and modeling efforts as we shift the scale of our research to map the hazards in a citizen's backyard. Our "GIS based modeling has helped to bring fire management to the individual parcels where we can identify property owners, both public and private, educate non-fire people about wildland fires and motivate neighbors to work together on wildfire management issues" (Rein, 2005 pers. comm.). It is this up close and personal scale where firefighters engage and extinguish fires. It is at a large-scale that vegetation can be mapped, monitored, and fuels mitigated. It is at this parcel-by-parcel scale where it is necessary to engage the public in preparing, protecting, and preventing WUI fires (Fig. 15).

President Clinton's initiatives in 2000 created the National Fire Plan (GAO-02-259). However, to combat and win over WUI fires, they must be fought in the backyard with local policy that addresses individual parcel characteristics.

NOTES

1. Mediterranean landscape is characterized by drought-tolerant plants, including pines and flammable shrubs that thrive in a climate of warm dry summers, mild wet winters, and relatively low annual rainfall.
2. "In reality, the very definition of 'extreme fire behavior' is framed within the context of human perceptions, with 'extreme' defining our limited ability to control it and its potential impact on firefighter safety." (Close, 2005)
3. A cell-based spatially static model is one where the value of each grid cell is assessed individually, without considering the impact of interaction with neighboring cells.
4. Common GIS tools include data synthesizing, classification, and interpolation techniques employed in thematic, choropleth, and isopleth mapping.

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REFERENCES

Acosta, T. (1994). The East Bay vegetation management consortium: A subregional approach to resource management and planning. *The Biswell Symposium: Fire Issues and Solutions* *in Urban Interface and Wildland Ecosystems*, Panel Discussion:... Urban Interface Problems, February 15–17.

Alexander, J. D., Seavy, N. E., Ralph, C. J., & Hogoboom, B. (2006). Vegetation and topographical correlates of fire severity from two fires in the Klamath-Siskiyou region of Oregon and California. *International Journal of Wildland Fire*, *15*, 237–245.

Alexander, M. E., & De Groot, W. J. (1988). *Fire behaviour in jack pine stands as related to the Canadian Forest Fire Weather Index (FWI) System*. Edmonton, Alberta: Canadian Forest Service, Northern Forest Centre.

Anderson, H. E. (1982). *Aids to determining fuel models for estimating fire behavior*. USDA For. Serv. Gen. Tech. Rep. INT-122, 22 p. lntermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Andrews, P. L. (1986). *BEHAVE: Fire behavior prediction and fuel modeling system-burn subsystem, Part 1*. USDA Forest Service General Technical Report INT-194.

Beer, T. (1990). The Australian national bushfire model project. *Mathematical Computer Modeling*, *13*(12), 49–56.

Berjak, S. G., & Hearne, J. W. (2002). An improved cellular automaton model for simulating fire in a spatially heterogeneous savanna system. *Ecological Modelling*, *148*, 133–151.

Bradley, M. (2002). This model can take the heat. *Science & Technology Review*, (November). Retrieved from http://www.llnl.gov/str/November02/Bradley.html.

Brown, A. L., Dayton, D. C., Nimlos, M., & Daily, J. W. (2001). Design and characterization of an entrained flow reactor for the study of biomass pyrolysis chemistry at high heating rates. *Energy & Fuels*, *15*, 1276–1285.

Burgan, R. E., & Rothermel, R. C. (1984). *BEHAVE: Fire behavior prediction and fuel modeling system-FUEL subsystem.* Gen. Tech. Rep. INT-167. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 126 pp.

California Board of Forestry (CBF). (2000). *California Fire Plan*.

Canadian Interagency Forest Fire Centre (CIFFC). (2004). Prometheus – the Canadian Wildland Fire Growth Model (CWFGM). Retrieved from http://www.firegrowthmodel.com/index.cfm.

CCSCE. (1999). Smart public investments for the california economy: Information and analysis for infrastructure planning, published by The Center for Continuing Study of the California Economy (CCSCE).

Claremont Canyon Conservancy. (2006). A citizen-based, non-profit organization for long-term stewardship of Claremont Canyon. Retrieved from http://ccconservancy.homestead.com/home.html.

Close, K. R. (2005). Fire Behavior vs. Human Behavior: Why the Lessons from Cramer Matter. Eighth International Wildland Fire Safety Summit, April 26–28, Missoula, MT.

Cohen, M., Etienne, M., & Rigolot, E. (2002). Modelling fuel distribution with cellular automata for fuel-break assessment. In: D. X. Viegas (Ed.), *Proceedings of the IVth International Conference on Forest Fire Research*, Luso, Coimbra, Portugal 2002/11/18-23. Rotterdam: Millpress.

Cohen, M., Rigolot, E., & Valette, J. C. (2004). From the vegetation to the inputs of a fire model: Fuel modelling for WUI management. Unpublished report.

Cova, T. (2005). Public safety in the urban–wildland interface: Should fire-prone communities have a maximum occupancy? *Natural Hazards Review*, *6*, 99–108.

Culler, D. E., Hill, J., Buonadonna, P., Szewczyk, R., & Woo, A. (2001). A network-centric approach to embedded software for tiny devices. *EMSOFT 2001*, October.

Doolin, D. M., & Sitar, N. (2005). Wireless sensors for wildfire monitoring. *Proceedings of SPIE Symposium on Smart Structures & Materials/NDE 2005*, San Diego, California, March 6–10.

Finney, M. A. (1998). *FARSITE: Fire Area Simulator-model Development and Evaluation.* Res. Pap. RMRS-RP-4, Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 47 p.

Finney, M. A., McHugh, C. W., & Grenfell, I. C. (2005). Stand and landscape effects of prescribed burning on two Arizona wildfires. *Canadian Journal of Forest Resources*, *35*, 1714–1722.

Goens, D. W. (1992). The Tunnel-Oakland Hills Fire Report, NWS. Internal Report on file at National Weather Service, Western Region Headquarters., Salt Lake City, UT.

Goens, D. W., & Andrews, P. L. (1998). Weather and fire behavior factors related to the 1990 Dude Fire near Payson, AZ. In: *Second Symposium on Fire and Forest*, Meteorology (pp. 153–158), 11–16 Jan 1998, Phoenix AZ. AMS.

Granito, J. (2003). Reducing the risk of wild land – urban interface fires issues and ideas papers. PERI Internet Symposium, Public Entity Risk Institute.

Hargrove, W. W., Gardner, R. H., Turner, M. G., Romme, W. H., & Despain, D. G. (2000). Simulating fire patterns in heterogeneous landscapes. *Ecological Modelling*, *135*, 243–263.

Hartzell, T. (2001). Implementation of the National Fire Plan. A statement before the Subcommittee on Forests and Forest Health, Committee on Resources, United States House of Representatives, March 8, 2001.Hills Emergency Forum (HEF). Retrieved from http://www.hillsemergencyforum.org.

Karafyllidis, I., & Thanailakis, A. (1997). A model for predicting forest fire spreading using cellular automata. *Ecological Modelling*, *99*, 87–97.

Kent, J. (2005). Interview with East Bay Regional Parks District General Manager.

Kim, B., & Landgrebe, D. A. (1991). Hierarchical classifier design in high dimensional, numerous class cases. *IEEE Transactions on Geoscience and Remote Sensing*, *29*, 518–528.

Kim, M. (2001). *A framework for dynamic planning: Evolving solutions to changing environmental problems*. Unpublished Ph.D. dissertation, University of California, Berkeley.

Klatt, T., & Mandel, D. (2005). *Fire mitigation program biannual progress report: Work sessions 2003–2004*. Berkeley: University of California January.

Koskinen, L., Astola, J., & Neuvo, Y. (1991). Soft morphological filters. In: *Proceedings of SPIE Symposium on Image Algebra and Morphological Image Processing*, (pp. 262–270).

Lawlor, M. (2005). Small systems, big business. *SIGNAL Magazine.* Retrieved from http://www.afcea.org/signal.

Luo, W. (2004). *A modeling approach to studying wildland urban interface fires.* Unpublished Ph.D. dissertation, University of California, Berkeley.

McArthur, A. G. (1966). Weather and grassland fire modeling. Commonwealth of Australia, Forest and Timber Bureau, Canberra, Leaflet No. 100.

McArthur, A. G. (1967). Fire modeling in eucalypt forests. Commonwealth of Australia, Forest and Timber Bureau, Canberra, Leaflet No. 107.

McKenzie, D., Peterson, D. L., & Alvarado, E. (1996). *Predicting the effect of fire on large-scale vegetation patterns in North America.* USDA Forest Service Research Paper PNW-489.

McKenzie, D., Prichard, S., Hessl, A. E., & Peterson, D. L. (2004). Empirical approaches to modeling wildland fire in the Pacific Nothwest region of the United States: methods and applications to landscape simulation. In: A. H. Perera, L. J. Buse & M. G. Weber (Eds), *Emulating natural forest landscapes: Concepts and applications* (pp. 85–97). New York: Columbia University Press.

Morvan, D., & Dupuy, J. L. (2001). Modelling of fire spread through a forest fuel bed using a multiphase formulation. *Combustion and Flame*, *127*, 1981–1994.

National Science Foundation (NSF). (2002). Adaptive real-time geoscience and environmental data analysis, modeling and visualization. ITR/IM-0121693 grant awarded by the National Science Foundation.

Pagni, P. (1993). Causes of the 20th October 1991Oakland Hills conflagration. *Fire Safety Journal*, *21*, 331–340.

Pister, K. S. J., Kahn, J. M., & Boser, B. E. (1999). Smart dust: Wireless networks of millimeter-scale sensor nodes. *1999 Electronics Research Laboratory Research Summary*.

Radke, J. (1995). Modeling urban/wildland interface fire hazards within a geographic information system. *Geographic Information Science*, *1*, 7–20.

Radke, J., Repetti A., & Xu, J. (2005). A web based geographic information platform to support fire modeling efforts in the wildland urban interface. *Presented at the 8th International Conference on GeoComputation*, Ann Arbor, Michigan.

Randall, C. K. (2003). Fire in the wildland-urban interface: understanding fire behavior. University of Florida, Institute of Food and Agricultural Sciences. Retrieved from http://edis.ifas.ufl.edu/FR138.

Rein, D. (2005). Quote from an Interview with East Bay Regional Parks District Fire Chief.

Rey, M. (2003). 2002 Wildfire season and wildfire threats for the 2003 season. A statement before the Committee on agriculture, U.S. House of Representatives, July 23, 2003.

Rollins, M. G., Morgan, P., & Swetnam, T. (2002). Landscape-scale controls over 20th century fire occurrence in two large Rocky Mountain (USA) wilderness areas. *Landscape Ecology*, *17*, 539–557.

Rothermel, R. C. (1972). A mathematical model for predicting fire spread in wildland fuels. U.S. Department of Agriculture, Forest Service, Research Paper INT-115. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Rothermel, R. C., & Rinehart, G. C. (1983). Field procedures for verification and adjustment of fire predictions. U.S. Department of Agriculture, General Technical Report INT-142. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Russell, W. H., & McBride, J. R. (2003). Landscape scale vegetation-type conversion and fire hazard in the San Francisco bay area open spaces. *Landscape and Urban Planning*, *64*, 201–208.

Scott, J. H., & Burgan, R. E. (2004). A new set of standard fuel models for use with Rothermel's spread model. *84th AMS Annual Meeting*, Seattle, WA.

Scott, J. H., & Burgan, R. E. (2005). *Standard fire behavior fuel models: A comprehensive set for use with Rothermel's surface fire spread model*. USDA Forest Service General Technical Report RMRS-GTR-153.

Soille, P., & Pesaresi, M. (2002). Advances in mathematical morphology applied to geoscience and remote sensing. *IEEE Transactions on Geoscience and Remote Sensing*, *40*, 2042–2055.

Taylor, A. H., & Skinner, C. N. (2003). Spatial patterns and controls on historical fire regimes and forest structure in the Klamath mountains. *Ecological Applications*, *13*, 704–719.

Todd, B. (1999). *User documentation for the wildland fire growth model and the wildfire display program*. Fire Research Network, CFS, Edmonton AB. 37 pp.

US Department of Agriculture (USDA). (2000). *Managing the impact of wildfires on communities and the environment: A report to the President in response to the wildfires of 2000*. Washington, DC.

US General Accounting Office. (1999). *Western national forests: A cohesive strategy is needed to address catastrophic wildfire threats*. GAO/RCED-99-65. Washington, DC.

US General Accounting Office. (2002). *Severe wildland fires: Leadership and accountability needed to reduce risks to communities and resources*. Report to Congressional Requesters. GAO-02-259. Washington, DC.

Warneke, B. A., Last, M., Leibowitz, B., & Pister, K. S. J. (2001). Smart dust: Communicating with a cubic-millimeter computer. *Computer Magazine*, January, 44–51.

Warneke, B. A., & Pister, K. S. J. (2002). Exploring the limits of system integration with smart dust. *Proceedings of 2002 ASME International Mechanical Engineering Congress & Exposition*, New Orleans, Louisiana, November 17–22.

Xu, J., & Radke, J. (2005). Further development of iMap for public feedback in the Claremont Canyon. Unpublished document.

Zhang, Y. (2001). Texture-integrated classification of urban treed areas in high-resolution color-infrared imagery. *Photogrammetric Engineering and Remote Sensing*, *67*, 1359–1365.

CHAPTER 12

COMMENTS ON THE PRESENT AND FUTURE OF WILDLAND FIRE SUPPRESSION DECISION-MAKING PROCESSES

Ben Machin and Mark Hentze

ABSTRACT

Public agencies entrusted with fire management in the western U.S. are faced with a decision each time a fire starts: should it be suppressed, or should it be left to burn? In some cases, fires that have not been rapidly staffed and suppressed have later proved very expensive and dangerous to suppress; and in other cases, fires that would never have caused large impacts are suppressed, missing an opportunity to reduce fuel loading and to cycle nutrients. In this chapter, the command structure through which these decisions are made is reviewed in basic terms, and a description is provided of how a fire goes from initial detection to being staffed by firefighters involved in fire suppression. Initial attack resources are discussed with an emphasis on the aerially delivered firefighters who often are responsible for suppressing remote fires. Finally, opportunities to improve the process of making fire suppression decisions are explored, and potential decision-support systems integrating firefighter knowledge with emerging technologies are discussed.

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INTRODUCTION

Across the American West, decades of successful fire suppression has resulted in increased fuel loading. During periods of drought, this fuel loading leads to increased fire risk and creates the conditions for dangerous and costly large fires. In the urban interface, human improvements act as additional fuel and add risk to human life, making fire suppression very complex and challenging. In attempts to reduce fuel loading, land managers have often prescribed fire and sometimes allowed naturally caused (lightning) fires to burn without suppression, a practice known as ‘‘wildland fire use’’ (WFU). WFU refers to ‘‘the management of naturally ignited fires to achieve resource benefits, where fire is a major component of the ecosystem,’’[1] or, more succinctly, letting fires burn, where safe and feasible, to achieve certain management goals. In many situations, these tactics have been successful, but there is an inherent risk in prescribing fire or managing naturally caused fire. These risks have sometimes materialized in the urban interface, where the presence of highly valued human improvements makes fires both expensive and dangerous. The 2002 Cerro Grande fire in New Mexico provided an example of the damage that can occur in the urban interface when prescribed fire planning and execution is not conducted properly, destroying many homes and threatening Los Alamos Nuclear Laboratory (NPS, 2000).

Farther from the urban interface, resource values tend to be lower, with fewer structures and less valuable timber because of less-suitable soils, higher elevations, and other factors. Small fires in these more remote areas initially tend to receive less public scrutiny but can often grow and evolve into large fires that threaten higher-resource-value areas. The 2002 Biscuit fire in southern Oregon is often cited as an example of this type of fire. Two small wilderness fires that later became the Biscuit fire were not attacked quickly in their early stages (over three days passed from detection to attack). When the fire was finally suppressed, the cost was $170 million, and over 500,000 acres had been burned (GAO, 2004a). There is some debate regarding why the initial attack was not rapid given that records indicate availability of Type 1[2] resources with the capability for rapid, aerially delivered initial attack (Corbet personal communication, 2005; Mansfield, 2004; Sheley, 2003).

With fuel loading increasing annually, the need for both prescribed fire and WFU is clear. While the positive effects of fire have long been discussed in concept and their use has had many proponents, both strategies are relatively newly applied, and it is clear that much is to be learned about their proper utilization (Biswell, 1999). Because more remote fires often involve lower resource values, they may offer outstanding opportunities to experiment with new ways of making suppression decisions so that potentially devastating fires are suppressed quickly and fires with little risk of becoming large and inflicting great damage are left to burn, reducing fuel loading and allowing nutrients to return to the soil.

THE WILDLAND FIREFIGHTING SYSTEM: AN INTRODUCTION

Every year, thousands of wildland fires are ignited in the forests and rangelands of the U.S. In 2005 for example, over 66,000 fires were reported to the National Interagency Fire Center (NIFC) in Boise, Idaho; this total was the lowest in more than 20 years (Leonard, 2005).

The United States Department of Agriculture (USDA) and United States Department of the Interior (USDOI) are the two primary departments of the executive branch of the federal government responsible for wildfire suppression on federal land. The National Wildfire Coordination Group assists in the coordination and cooperation among all the federal agencies that suppress wildland fire. Within the USDA, the Forest Service (FS) has primary responsibility for wildlife management and within the USDOI, the Bureau of Land management (BLM), National Park Service (NPS), Bureau of Indian Affairs (BIA), and U.S. Fish and Wildlife Service (FWS) share responsibility. These agencies work cooperatively and aid each other in fire suppression and share the dispatching resources that are responsible for coordinating fire staffing.

Three tiers exist within the dispatch system: the national level, the geographic level, and the local level. The national level is the National Interagency Coordination Center (co-located with NIFC); at the geographic level are 11 Geographic Area Coordination Centers; and at the local level there are multiple local dispatch centers. The local dispatch center is responsible for dispatching fires on all land that has been designated, by prior agreement, as part of the local area; this may include lands managed by multiple federal or state agencies. While the dispatch system is responsible for coordinating staffing and responding to fire suppression needs as relayed by firefighters on scene, the decisions regarding suppression are made by the "duty officer" responsible for the portion of land in which the fire starts. For example, the FS often divides National Forests into districts; each district has a Fire Management Officer (FMO) who is responsible for supervising fire suppression. This duty officer makes the decision to suppress a fire. During periods of high fire danger, a Multi-Agency Coordination group

(MAC) at the geographical level may convene to assist in fire suppression prioritization and allocation of suppression resources.

"WHERE THERE'S SMOKE, THERE'S FIRE": FIRE DETECTION

When a fire starts in a remote area and the smoke becomes visible to the human eye, there are three primary ways in which detection occurs: fire-lookout towers, reconnaissance aircraft, and ground party reports. After a fire has been detected, it is reported to the appropriate local dispatch center, and resources are dispatched to the fire. The type and number of resources dispatched to the fire is determined with the aid of an Annual Operating Plan (AOP). The AOP is developed, updated, and approved annually within the local areas and with cooperation among the various agencies in the local areas. The AOP gives direction for dispatching the number and type of suppression resources to the fire based upon current fire behavior, predicted fire behavior, and the location of the fire. Often, usually after a lightning storm, numerous fires are ignited, and there may not be enough resources available locally or nationally to immediately begin suppression operations on all of the fires. During periods of multiple fire starts, the FMO must work directly with the local dispatch center and prioritize fire suppression efforts with direction from the AOP. During periods of high fire danger or multiple fire starts, direction for suppression prioritization and allocation of resources may also come from the MAC group at the geographic or national levels. A qualified Incident Commander (IC) is always dispatched to the fire, and when the IC arrives on scene, he is then responsible for determining what, if any, additional suppression resources are necessary to successfully suppress the fire.

Throughout the western U.S., fire-lookout towers are strategically located in rangelands and forest lands and are staffed during fire season by personnel ("lookouts") who are trained to visually detect the smoke from fires and to report on their characteristics and approximate location. The lookout towers are located with sensitivity to topography so that the best view of the land is made available to the lookout. When the lookout detects a fire, its location is determined with the use of a map and an alidade, a sighting apparatus seated on a plane table and used in angular measurement. Using the alidade, the lookout determines the approximate location of the fire and provides a report via radio to the dispatch center. In addition to location, this report generally includes approximate size of the fire, its position on slope, adjacent fuels, current and potential fire behavior, and smoke characteristics.

Reconnaissance aircraft are generally small planes and are most often used following lightning storms or during periods of high fire danger. Lightning strikes are electronically detected and analyzed using a system that includes ground sensors, satellite transmitters, and central data processors (Vaisala, 2005). This data is almost immediately displayed via the Internet, allowing detection resources (including reconnaissance planes) to focus on areas that have received a high number or density of cloud-to-ground strikes (BLM, 2005). Reconnaissance aircraft are most often staffed by a pilot and an agency employee with fire experience. The reconnaissance planes will most often fly in a pattern or a grid in search of wildland fires. When a wildland fire is detected, the agency employee determines the location of the fire with the use of maps and a Global Positioning System. The agency employee then provides the dispatch center a report similar to that provided by the lookout in the fire tower.

Ground party reports can come from agency personnel on the ground on fire assignments or on other work or via private individuals.

"TO SUPPRESS OF NOT TO SUPPRESS": THE SUPPRESSION DECISION

After a fire has been reported to the local dispatch center, the suppression-decision process begins. Dispatch personnel first consult the AOP and the corresponding maps, locating the fire and determining if it falls within a previously mapped area. WFU areas are generally uncommon, and they are designated at the local level and not tracked or mapped at the national level. Fires that are not located within WFU areas are virtually always suppressed. During periods of low to moderate fire activity, the local dispatch center may dispatch the appropriate type and number of resources to suppress the fire with the guidance of the AOP and without further input from the duty officer (often the FMO), the geographic or national level, or other land managers.

After a lightning storm, dozens or even hundreds of fires may be ignited in an area, and during these times, there may not be enough resources available locally or nationally to suppress all of the fires. Due to the lack of resources, not all of the fires are quickly suppressed, and some of the fires may grow to a large size and destroy or threaten to destroy valuable resources. During these times, fire suppression must be prioritized; this is generally the responsibility of the duty officer using direction given in the AOP. During times of high fire danger or multiple starts, a MAC group at the local or geographic level may convene and give direction in fire suppression prioritization and allocation of resources. The prioritization is based upon the type and number of resources threatened by the fire and by predicted spread potential. Predicted fire behavior and rate of spread are based on a variety of factors including fuel type, fuel moisture, steepness, slope position, slope aspect, and local weather such as temperature, humidity, and winds.

If allowing a fire to become a WFU fire is an option (based in part on previously mapped WFU areas) a wildland fire implementation plan (WFIP) becomes more important. Each WFIP can stand alone as an implementation plan, and progression from one stage to the next is predicated upon fire activity, potential fire duration, and relative risk (National Fire and Aviation Executive Board, 2005). The WFIP includes three stages: stage one includes strategic fire size-up, periodic assessment (sets frequency and nature of assessments regarding whether to suppress or monitor for resource benefits), and documentation of the decision-making process; stage two defines management actions including objectives, a fire situation analysis, management actions, estimated costs, and periodic fire assessment (this determines if the fire stays in stage two, moves to stage three, or becomes a suppression situation); stage three is designed to respond to an escalating fire situation with prolonged duration and increased need for management resources. Specific targets are assigned to each stage for maximum completion timeframes: 8 h for stage one, 48 h for stage two, and 7 days for stage three (National Fire and Aviation Executive Board, 2005). If fires that are designated for WFU pass set thresholds and a suppression approach is selected, a wildland fire situation analysis (WFSA) is always required. While WFSA standards vary by agency, the primary purpose is to provide documentation and to develop an effective strategy for suppression.

Although WFUs are an important method of managing naturally caused fires, the designation is not used frequently. In 2005, for example, only approximately 71 of 1,136 large fires reported to NIFC were WFU fires (Leonard, 2005).

INITIAL ATTACK AND THE INCIDENT COMMANDER: A BRIEF SYSTEM OVERVIEW

Once the decision has been made to suppress a fire, the dispatch center places an order with the initial attack resource or resources deemed to be the best fit for the fire. Potential available resources include fire engines of various size classes, hand crews of 2 to 20 people, bulldozers and tractors with plows for constructing fire lines, light and heavy air tankers that drop fire retardant on the fire or adjacent fuels, helicopters for transporting personnel and dropping water on the fire, and aerially delivered firefighters.

Once the local dispatch center has chosen the best resource type for fire suppression, they dispatch the nearest resource of that type regardless of agency affiliation. For example, if the closest resource to a fire on BLM land is an FS fire engine, then the FS fire engine is dispatched to the fire. During periods of multiple starts, periods with potential for multiple starts or periods of high fire danger, even if the AOP suggests multiple resources should be dispatched to the fire, it is possible that only one or two resources are dispatched. The other resources may be kept available for other new starts on the same day or the following days. Engines and hand crews tend to be used where access via wheeled vehicle or short hikes is feasible.

In roadless areas or where access is difficult or time-consuming via roads, aerially delivered firefighters are often used. The two primary types of aerially delivered personnel are helicopter crew members and smokejumpers. Helicopter crew members may be landed near the fire, or properly trained personnel – called heli-rapellers – may rappel from the helicopter if there is not an adequate area to land the helicopter near the fire. Smokejumpers are delivered to fires via fixed-wing aircraft and parachute (Fig. 1). Both the fixed-wing aircraft and helicopters travel at high speeds, often allowing them

Fig. 1. Smokejumpers Landing to Respond to a Wildfire.

to arrive on scene in a shorter period of time than firefighters who must drive to the fire. It is often difficult to locate a fire from the ground and to determine the best access to the fire via the road system; aerially delivered resources have the advantage of locating the fire from the air and being delivered in close proximity to the fire. Aerially delivered firefighters have been subject to agency-sponsored analysis; a study completed in 1999 confirmed that smokejumpers in particular provide a cost-effective means of reaching and suppressing fires (FS, 1999). Aerially delivered firefighters are Type 1 resources, are stationed at air bases, and have their own internal management structures. They have a self-sufficient approach, developing their own techniques for access (e.g., rappel systems for descending from trees when necessary), making their own specialized gear (e.g., Kevlar protective suits), and arriving at fires with enough water, food, and tools to stay for several days without support. When necessary, resupply is available to aerially delivered firefighters – via para-cargo or helicopter sling load – making extended suppression efforts feasible and reducing the burden on local land managers to provide logistical support. Fire suppression techniques that are used once firefighters arrive on scene include creating fuel breaks (“fireline”) by removing flammable material and exposing mineral soil (Fig. 2), burning material between the fuel break and the fire (known as

Fig. 2. Creating a Back Country Fuel Break by Felling Trees.

Fig. 3. "Back-firing" to Eliminate Fuels Between the Fuel Break and the Wildfire.

"burning out," or "back-firing," shown in Fig. 3), and using aerial resources to deliver water or fire retardant.

Regardless of resource type, a qualified IC is always dispatched to the fire as part of the suppression team. The arriving IC assumes responsibility for determining what additional suppression resources, if any, are necessary and appropriate to suppress the fire. The initial fire size-up given to the local area dispatch by the reconnaissance aircraft, lookout tower, or other source is not always accurate, and when the IC arrives on the scene, they can more accurately predict fire behavior, potential for fire growth, and what resources will be needed to suppress the fire. The IC or other personnel on the fire may also identify threatened valuable resources that were not identified before. Not all of the available suppression resources are appropriate or usable for each fire (e.g., a bulldozer or tractor with a plow is not appropriate for use in designated wilderness areas or near archeological sites). The IC must consider all of these factors – current fire size, the potential for spread, threatened resources, and the appropriate type of resources for the fire – before ordering the type and number of additional resources necessary to suppress the fire. The IC's request may or may not be granted by the local dispatch center based upon availability of additional resources and the potential for new starts in the area.

Under normal circumstances, there is no system in which the IC can recommend that the fire suppression approach be suspended and that designating the fire as a WFU fire be considered. If the IC examines the fire and determines that there is low spread potential, moderate fire behavior, little value in the threatened resources, and a need for fuel-loading reduction, there is no system through which to channel this information and to reconsider the decisions to suppress the fire. Anecdotes exist among initial attack firefighters, especially aerially delivered firefighters working in remote areas, of low-risk fires that were suppressed when risk of spread and resource values were low. Through an informal survey of aerially delivered firefighters, examples of this type were cited including fires naturally entrapped between rock slides and fires bordered by waterways.

AN OPPORTUNITY FOR THE INTEGRATION OF NEW TECHNOLOGIES

Public agencies entrusted with ecosystem management and fire suppression are already making efforts to increase the understanding and utilization of the WFU designation and management approach through workshops and recently revised manuals (National Fire and Aviation Executive Board, 2005). However, systems for determining potential environmental impacts of prescribed and WFU fires have been criticized for their lack of ability to predict potential impacts (GAO, 2004b). It is clear both from official reports of this nature as well as feedback from firefighters that the current system for designating WFU fires could use improvement. In particular, the rapidly developing field of Geographic Information Systems (GIS) has the potential to greatly aid in decision making. It is perhaps with this potential in mind that the FS has recently begun a project to develop a Wildland Fire Decision-Support System that will integrate GIS functionality to help reengineer the WFSA and WFIP processes (FS, 2005). In addition, numerous unrelated studies aimed at using GIS to predict fire spread and make management decisions are underway (see Chapter 11 by Radke in this volume for illustrations of the use of integrated GIS fire models for simulating fire behavior and planning mitigation).

Systems that use GIS to integrate spatial data with fire risk or fire spread models could be very helpful in making more-informed decisions about which fires to suppress and which to let burn. Factors that will be important to map or model include but are not limited to fuel loading, fuel moisture, weather, wind, slope, aspect, fire history (including previously burned areas), and resource values (e.g., structures, timber, historically significant areas, threatened and endangered species). The challenge is to gather or develop the necessary data and to integrate these data into a central decision-support system.

Once the basic decisions-support system is in place, it would be made much stronger by the integration of human intelligence, or ''ground truthing,'' conducted by firefighters on site. This has been used in a basic manner by the Los Angeles County (California) Fire Department, which is using a system to map fire perimeters in a GIS within the first 45 min of being on scene (Koegler, 2005). This approach could be broadened to encompass data collection by firefighters and a system for integrating these data into the centrally located decision-support system.

Systems that incorporate human intelligence and GIS data can assist in making suppression decisions and prioritizing when new fires are frequent and resources are limited. However, in order for efficient systems of this type to be broadly deployed, they will need extensive testing, as previous experience with prescribed fires has shown. With their high level of average experience, self-sufficient management structure, and likelihood of managing fires in remote areas where resource values are generally lowest, aerially delivered firefighters present land managers with an extraordinary opportunity to develop and pilot test decision-support systems with a relatively low degree of risk. Having these firefighters involved in the decision-making process will also provide a decidedly unscientific ''sanity-check'' and help land managers to develop feedback loops and ''buy-in'' that may make active use of the system far more likely.

By deploying systems for making intelligent suppression decisions in the more-remote areas using firefighting resources adapted to these conditions, the risk of devastating urban interface fires will over time be reduced as fuel loading decreases. With reduced fuel loading will come a decreased chance that fires starting in the more remote areas can grow to be uncontrollable and spread into more urban, higher-resource-value areas. In addition, testing systems in areas of low resource value will lead to their refinement; once refined, they may become more applicable to more urbanized areas. A more sophisticated system, combined with the firsthand input of wildland firefighters on scene, would assist public agencies greatly in their quest to better understand and manage fire-adapted ecosystems.

NOTES

1. Quoted from the USDA Forest Service at http://www.fs.fed.us/fire/fireuse/wildland_fire_use/use_index.html.

2. Type 1 resources are those that have a greater overall capacity. They are often are controlled nationally from the National Interagency Fire Center (NIFC) as opposed to by managers of the local district, forests, or regions with the goal of avoiding local shortages of personnel. Type 1 resources include interagency hotshot crews, helicopter rapellers, and smokejumpers.

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REFERENCES

Biswell, H. (1999). *Prescribed burning in California Wildlands Vegetation Management*. Berkeley, CA: University of California Press. p. 274.

Corbet, M. (2005). Personal communication, 10/17/05. Official record-keeper and Squad Leader, Redmond Smokejumpers.

General Accounting Office (GAO). (2004a). Biscuit fire analysis of fire response, resource availability, and personnel certification standards (report to congressional requesters, GAO-04-426).

General Accounting Office (GAO). (2004b). Wildland fires – Forest Service and BLM need better information and a systematic approach for assessing the risks of environmental effects. Report to congressional requesters, GAO-04-705.

Koegler, L. (2005). Initial Attack GIS Supports IC Decision Making (County of Los Angeles Fire Department). Retrieved December 2005, from http://www.esri.com/news/arcuser/0703/initial1of2.html.

Leonard, C. (2005). Personal communication 1/03/2006. National Interagency Fire Center Fire Intelligence Staff.

Mansfield, C. R. (2004). *The biscuit fire – consequences of forest management decisions*. Los Alamos, NM: Coyote Tales Publishing.

National Fire and Aviation Executive Board. (2005). *Wildland fire use implementation procedures reference guide*. US Dept of Agriculture and US Dept of Interior.

National Park Service (NPS). (2000). Cerro Grande Prescribed Fire Investigative Report, May 18, 2000. National Interagency Fire Center, Boise, ID.

Sheley, C. (2003). How the West was lost – is that your money burning? *Smokejumper Magazine*, January 2003. [This article followed up online in an op-ed entitled "A final look at the Biscuit fire – is the initial attack system broken?,"]. Retrieved 2005, from http://www.smokejumpers.com/opinion/item.php?opinion_id=263.

U.S. Bureau of Land Management (BLM). (2005). The BLM lightning display system is available online (password required) at http://www.nifc.blm.gov/cgi/nsdu/Lightning.cgi/Page/ViewSelect.

USDA Forest Service. (1999). Aerially Delivered Firefighter Study. Retrieved December 2005, from http://www.fs.fed.us/fire/adff/.

USDA Forest Service. (2005). Wildland Decision Support System (WFDSS) Project (briefing paper). Retrieved December 2005, from http://www.fs.fed.us/fire/wfsa/.

Vaisala Group. (2005). Explanation of lightening detection system. Retrieved December 2005, from http://www.vaisala.com/businessareas/measurementsystems/thunderstorm/knowledgecenter/aboutnldn.

CHAPTER 13

CLIMATE VARIABILITY, CLIMATE CHANGE, AND WESTERN WILDFIRE WITH IMPLICATIONS FOR THE URBAN–WILDLAND INTERFACE

William S. Keeton, Philip W. Mote and Jerry F. Franklin

ABSTRACT

Climate change during the next century is likely to significantly influence forest ecosystems in the western United States, including indirect effects on forest and shrubland fire regimes. Further exacerbation of fire hazards by the warmer, drier summers projected for much of the western U.S. by climate models would compound already elevated fire risks caused by 20th century fire suppression. This has potentially grave consequences for the urban–wildland interface in drier regions, where residential expansion increasingly places people and property in the midst of fire-prone vegetation. Understanding linkages between climate variability and change,

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therefore, are central to our ability to forecast future risks and adapt land management, allocation of fire management resources, and suburban planning accordingly. To establish these linkages we review previous research and draw inferences from our own retrospective work focused on 20th century climate–fire relationships in the U.S. Pacific Northwest (PNW). We investigated relationships between the two dominant modes of climate variability affecting the PNW, which are Pacific Decadal Oscillation (PDO) and El Niño/Southern Oscillation (ENSO), and historic fire activity at multiple spatial scales. We used historic fire data spanning most of the 20th century for USDA Forest Service Region 6, individual states (Idaho, Oregon, and Washington), and 20 national forests representative of the region's physiographic diversity. Forest fires showed significant correlations with warm/dry phases of PDO at regional and state scales; relationships were variable at the scale of individual national forests. Warm/dry phases of PDO were especially influential in terms of the occurrence of very large fire events throughout the PNW. No direct statistical relationships were found between ENSO and forest fires at regional scales, although relationships may exist at smaller spatial scales. However, both ENSO and PDO were correlated with summer drought, as estimated by the Palmer Drought Severity Index (PDSI), and PDSI was correlated with fire activity at all scales. Even moderate ($\pm$0.3°C decadal mean) fluctuations in PNW climate over the 20th century have influenced wildfire activity based on our analysis. Similar trends have been reported for other regions of the western U.S. Thus, forest fire activity has been sensitive to past climate variability, even in the face of altered dynamics due to fire suppression, as in the case of our analysis. It is likely that fire activity will increase in response to future temperature increases, at the same or greater magnitude as experienced during past climate variability. If extreme drought conditions become more prevalent we can expect a greater frequency of large, high-intensity forest fires. Increased vulnerability to forest fires may worsen the current fire management problem in the urban–wildland interface. Adaptation of fire management and restoration planning will be essential to address fire hazards in areas of intermingled exurban development and fire-prone vegetation. We recommend: (1) landscape-level strategic planning of fire restoration and containment projects; (2) better use of climatic forecasts, including PDO and ENSO related predictions; and (3) community-based efforts to limit further residential expansion into fire-prone forested and shrubland areas.

INTRODUCTION

Wildfire dynamics in portions of the western United States have been dramatically altered from pre-European settlement conditions. Increased fire hazards due to 20th century fire suppression and other human activities have serious implications for the urban–wildland interface, including risks to human safety and property. These trends necessitate difficult resource management and planning decisions as communities and housing expand into previously undeveloped, fire-prone areas (Cova, Sutton, & Theobald, 2004; GAO, 1999). Superimposed on these trends are the potential effects of climate change, which are predicted to increase the frequency and severity of drought conditions (Brown, Hall, & Westerling, 2004) and extreme fire weather (McKenzie, Gedalof, Peterson, & Mote, 2004) across the U.S. southwest, interior Great Basin, and northern Rocky Mountain region in particular (Brown et al., 2004). Climate-related fire risks have the potential to compound the present fire management problem along the urban–wildland interface. Understanding linkages between climate variability and change, therefore, are central to our ability to forecast future risks and adapt land management, allocation of fire management resources, and suburban planning accordingly. To establish these linkages we review previous research and draw inferences from our own work focused on 20th century climate–fire relationships in the U.S. Pacific Northwest (PNW, Fig. 1).

In the western United States interactions between climate variability and fire are likely to be important drivers of forest ecosystem responses to climate change. For this chapter we define climate variability as fluctuations in climatic conditions over multiple time scales and primarily attributed to natural processes. Climate change is treated as future changes in the global climate system, primarily related to anthropogenic causes (IPCC, 2001). Our work has focused on large-scale modes of climatic variation over the tropical and north Pacific Ocean, including El Niño/Southern Oscillation (McPhaden et al., 1998) and the Pacific Decadal Oscillation (PDO) (Mantua, Hare, Zhang, Wallace, & Francis, 1997), respectively. We have used a retrospective approach to understand how fire frequency and intensity responded to past climatic fluctuations. This improves our ability to predict how disturbances, and related fire risks along the urban–wildland interface, will respond to future climate changes, especially alterations of climate-related stressors, like extreme drought events, for which we can find historic analogues.

Relationships between the PDO and fire activity in the interior Northwest have been identified by previous studies that relied on dendrochronological

Fig. 1. The Climate Impacts Group focuses on the Columbia River Basin (Outlined) and the States of Washington, Oregon, and Idaho. Figure Courtesy of Robert A. Norheim, Climate Impacts Group, University of Washington, Seattle, WA.

(i.e. tree ring) methods to establish fire and climate histories extending back to 1700 AD (Gedalof & Smith, 2001; Hessl, McKenzie, & Schellhaas, 2004). Other recent work has used climate projections to predict possible 21st century changes in the timing, duration, and intensity of climate variables related to western U.S. forest fire danger (Brown et al., 2004; McKenzie et al., 2004). Both approaches have found clear linkages between fire risks, past climate variability, and future climate change, with extended drought during the fire season acting as the fundamental climate mechanism associated with elevated fire hazards. Our retrospective research attempts to support these findings and predictions using historical, documented records of 20th century fire activity and direct measurements of climate variability. This work was undertaken as part of the regional assessment of climate variability and climate change impacts on the PNW (Mote et al., 2003), part of the National Assessment program (NAST, 2000). Selected elements and summations of this work, undertaken by the interdisciplinary Climate Impacts Group at the University of Washington, have previously been reported elsewhere (Keeton, Franklin, & Mote, In press; Mote et al., 1999a; Mote, Keeton, & Franklin, 1999b; Mote et al., 2003; Parson et al., 2001), but this paper is the first to report our findings in full.

Climate change is predicted to have direct and indirect effects on forest ecosystems (Fig. 2). Direct effects include altered physiological processes due to changes in temperature and precipitation regimes as well as CO_2 enrichment. These are predicted to cause changes in the distribution, composition, and productivity of forest ecosystems nationwide (NAST, 2000). Potential indirect effects include altered natural disturbance regimes, including changes in the frequency, intensity, and spatial extent of fire, insect, disease, and wind disturbances (Keeton et al., In press).

Over the near-term, climate-driven natural disturbances may be even more important than the direct effects of climate change in causing abrupt or rapid forest ecosystem responses (Fosberg, Mearns, & Price, 1992; Overpeck, Rind, & Goldberg, 1990; Ryan, 1991). Changes in vegetation composition and structure may be especially rapid on sensitive sites or near the limits of species' ranges (Allen & Breshears, 1998; Brubaker, 1988).

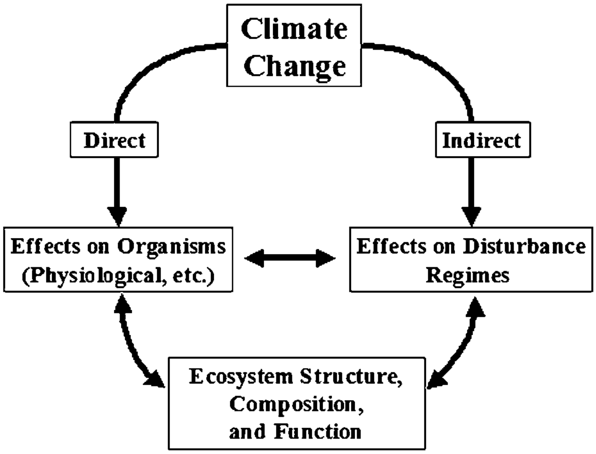

Fig. 2. Climate Change is Predicted to Impact Forested Ecosystems both through Direct Effects on Organisms and Indirect Effects on Natural Disturbance Regimes (e.g., Fire, Insects, Pathogens, and Wind). Feedback relationships among these pathways of change contribute collectively to increased fire risks in the urban–wildland interface. Modified from Franklin et al. (1991).

Established forests often can resist climatic variability both because they ameliorate microclimatic conditions within the forested ecosystem and because mature trees can survive extended periods of less favorable climate (Brubaker, 1986; Dale & Franklin, 1989; Franklin et al., 1991). High-intensity disturbances, however, have the potential to reset stand development to the establishment stage (Franklin et al., 2002), which is the stage most sensitive to adverse environmental conditions, such as drought and heat (Brubaker, 1986). Stand-replacing disturbances are likely to cause more rapid transitions in ecosystem composition and structure over the near-term than are the direct changes in tree growth rates alone (Franklin et al., 1991; Overpeck et al., 1990). It is, therefore, critical to understand relationships between disturbance dynamics and climate variability if we are to accurately predict both rates and pathways of future ecosystem change as well as associated fire risks.

While mean climate varies considerably across the Northwest, interannual variations in climate are strongly correlated within the region (Mote et al., 2003). Warm versus cool years tend to be experienced similarly throughout the region. This regional coherence permits us to focus on temporal fluctuations in the regional average anomalies. Year-to-year global climatic variations are dominated by El Niño/Southern Oscillation (ENSO), an irregular oscillation of the tropical atmosphere and ocean with a period of 2 to 7 years (McPhaden et al., 1998). Interannual variations in forest fire activity in the U.S. Southwest are significantly correlated with the ENSO phenomenon (Swetnam & Betancourt, 1990). In the Northwest, the influence of ENSO on regional climate is rivaled by another such irregular variation, this one in the north Pacific basin: the Pacific Decadal Oscillation (PDO). By calculating empirical orthogonal functions (EOFs) of monthly Pacific sea surface temperature (SST) north of 20° N, Mantua et al. (1997) identified the PDO as the dominant mode of variability on interannual timescales in the north Pacific (Fig. 3).

The PDO is a pattern of Pacific SST anomalies whose positive phase is associated with cold anomalies in the central Pacific and warm anomalies along the west coast of North America. It resembles the SST pattern that usually coincides with ENSO, but has different temporal characteristics. A time series of the loading of the first EOF (Fig. 3) exhibits slow variations in which the dominant sign remains the same for 20–30 years. It was in the negative phase from about 1900 (when a few reliable SST measurements began to be available) to 1925 and from 1945 to 1977, and in the positive phase from 1925 to 1945 and from 1977 to 1999. Since 1999 PDO has returned to its negative phase. Warm phases of ENSO and PDO coincide

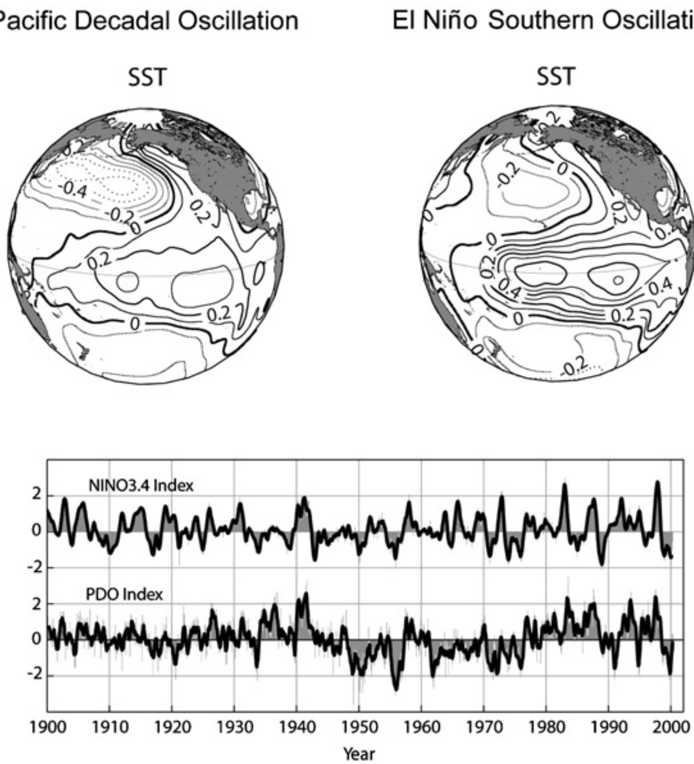

Fig. 3. Spatial Pattern of Anomalies in Sea Surface Temperature (SST; degrees Celsius) Associated with the Warm Phase of PDO (Left) and ENSO (Right). Note that the main center of action for the PDO is in the north Pacific, while the main center of action for ENSO is in the equatorial Pacific. Time histories of the PDO and ENSO patterns are shown below. When the Nino 3.4 or PDO index is positive, the SST anomalies resemble those shown in the contour plots. When the index is negative, the SST anomalies would be reversed. Images provided by the University of Washington, Climate Impacts Group.

with winter and spring weather that is warmer and drier than average in the PNW, and cool phases coincide with cooler, wetter weather.

We investigated relationships between the two climate time series, ENSO and PDO, and 20th century fire activity in the PNW at multiple spatial scales. Our hypothesis was that relationships are scale dependent due to spatial variation in mechanistic relationships linking climate and fire. These two climate patterns (ENSO and PDO) are useful for our purposes in at least two ways. First, together they provide robust predictability in seasonal forecasts for the region. Second, the multi-decadal timescale of the PDO may provide a useful surrogate for anthropogenic climate change. For forest ecosystems the persistence of warmer-drier or cooler-wetter conditions over 20–30 years is likely to produce a higher magnitude response than do single, anomalous years (Mote et al., 2003).

METHODS

We analyzed relationships between 20th century forest fire activity and climatic variability at three spatial scales: regional (USDA Forest Service Region 6: Washington and Oregon), individual states (Idaho, Oregon, and Washington), and individual national forests within the PNW. These geopolitical scales were defined by the available historic fire datasets. We selected 20 national forests for analysis that are representative of the region's physiographic provinces and precipitation divisions.

We collected data on forest fires in Idaho, Washington, and Oregon and correlated the year-to-year variations with ENSO and PDO. The fire data include area burned, area monitored, and number of lightning vs. human-caused fires. Fire data time series were compiled from USDA Forest Service annual forest fire reports and data from the National Archives covering 1905–2000 for the region (Fig. 4), 1916–2000 for individual states, and 1922–2000 for individual national forests. They are considered to be independent data sets, because state- and regional-level data series were collected using different methods and, consequently, do not sum to increasingly coarser scales. For the state and regional data, we constructed Burn Area Indexes (BAI) by normalizing the area burned each year by the area monitored in that year, since this fluctuated over time. The indexes were calculated as follows:

$$\mathrm{BAI} = \left(\frac{\text{hectares burned}}{\text{hectares monitored}}\right) \times 10,000$$

As a measure of ENSO we used the Nino3.4 index. For the PDO we used six-month means (October–March or "winter," and April–September or "summer") of the monthly time series generated by Mantua et al.'s (1997) EOF analysis and subsequent monitoring.

Our correlation analyses also included comparisons between climate and fire time series and the Palmer Drought Severity Index (PDSI), which is an estimate of accumulated soil moisture deficit (Palmer, 1965). We used PDSI

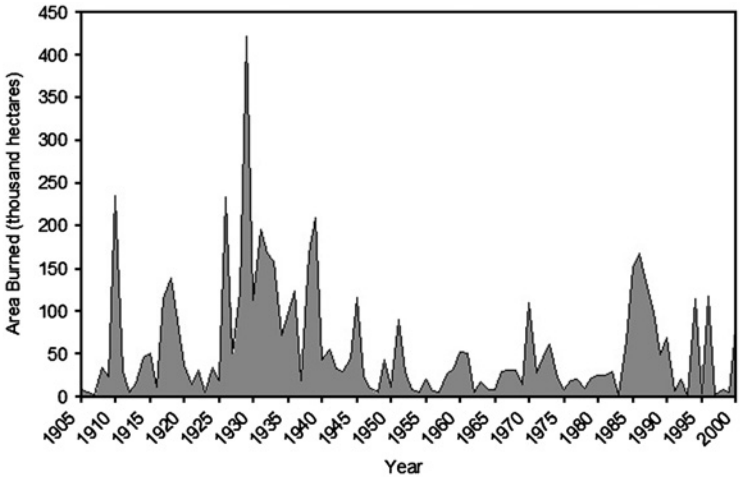

Fig. 4. Area Burned by Forest Fires in USDA Forest Service Region 6 (Washington and Oregon) from 1905 to 2000. The data shown have not been normalized to account for fluctuations in the area monitored over time.

as an indicator of drought conditions, our hypothesized intermediary mechanism. Linear regression analysis was used for statistical testing of fire data against time series for ENSO, PDO, and PDSI. Residuals were examined to confirm assumptions of normality using the Wilk–Shapiro test. Significance levels were estimated using Monte Carlo simulations. We used a 90% confidence level to determine significance due to the high degree of noise inherent in climate data. We used the Durban–Watzin test, performed on the residuals resulting from each regression combination, to identify cases where correction for autocorrelation was necessary. We confirmed these results using an autocorrelation test developed by Bretherton, Widmann, Dymnikov, Wallace, and Blade (1999), and corrected degrees of freedom and significance levels accordingly.

Scatter plots of BAI by year showed discrete thresholds of separation between years in which relatively small total areas were burned and years in which large areas were burned. We used these thresholds to define "large-fire" years at the scale of states (>80,000 ha burned) and unit of the National Forest System (>400 ha burned). We conducted additional analysis on the number of "large-fire" years at these scales that occurred during either warm/dry or cool/wet phases of ENSO or PDO, grouped as categorical data into observed vs. expected distributions. To test for differences between distributions we used a log likelihood-ratio goodness of fit (*G*-test) with the Yates correction for continuity. This test approximates the X^2 statistic, but it is more robust than the Chi-square goodness of fit test when certain conditions are met (Zar, 1996), as was the case with our data.

RESULTS

Pacific Decadal Oscillation

Regional scale BAI is closely correlated with the PDO (Table 1). Forest fires were much more extensive in the USDA Forest Service Region 6 during the 1925–1945 warm phase of PDO than during the cool phases before and after that (Mote et al., 1999b). The resurgence of fire activity in the late 1980s was consistent with the warm–dry phase of the PDO, but also correlates with increased fire hazards due to fire suppression. When year-to-year values of the PDO are considered, however, we find a significant correlation with BAI. The winter PDO index has a correlation coefficient of 0.31, which is statistically significant at the 99% level using Monte Carlo methods. Summer PDO was not significantly correlated with BAI.

The increased tendency for forest fires in warm-phase PDO years holds at finer spatial scales (Table 1). Warm-phase PDO is positively correlated with BAI for Washington ($P = 0.003$). However, for Idaho ($P = 0.055$) and Oregon ($P = 0.062$) this relationship was only moderately strong, which signals possible interactions with other scale-dependent sources of variability. At the scale of individual states, correlations with PDO shift by state when we restrict our analysis to exceptional years in which very large areas

Table 1. Statistical Results Correlating Pacific Decadal Oscillation against Burn Area Index at Regional (1905–2000) and State (1916–2000) Scales. Results of Autocorrelation Analyses of Time Series are also Reported.

	USFS Region 6	Oregon	Washington	Idaho
Correlation coefficient (*R*)	0.31	0.211	0.42	0.21
Degrees of freedom	89	80	80	80
P value	0.003	0.062	<0.001	0.055
Durban Watzin (DW) statistic	1.622	1.533	1.688	2.245
DW critical value at 99% significance level	1.550	1.530	1.530	1.530
Autocorrelation probability (%)	<1	<1	<1	<1

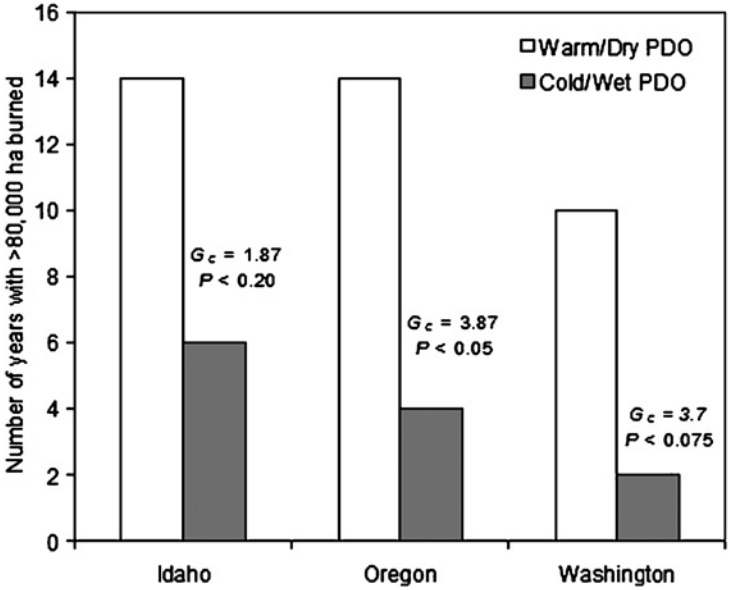

Fig. 5. The Number of Years with $>80{,}000$ Hectares Burned During with either Warm/Dry (Positive) Phases or Cool/Wet (Negative) Phases of Pacific Decadal Oscillation: 1916–2000. Statistical results are based on the log likelihood ratio goodness of fit test.

(e.g., $>80{,}000$ hectares) were burned (Fig. 5). The differences in numbers of large-fire years for warm-dry vs. cool-wet PDO are statistically significant ($\alpha = 0.10$) for Oregon ($P<0.05$) and Washington ($P<0.075$), although not for Idaho ($P<0.2$). Annual area burned at the scale of individual national forests is also more prevalent during the warm phases of PDO, and was correlated ($\alpha = 0.05$) with the values of the PDO for 8 of the 20 national forests selected (Table 2). All of the national forests positively correlated with warm-phase PDO were either in the semi-arid interior Northwest, the southern Cascade Range, or the Klamath-Siskiyou Mountains. When we restrict our analysis to extreme fire years, for instance those years in which greater than 400 hectares burned on an individual national forest, the warm phase of PDO generally increases the likelihood of large fires, although these relationships are only statistically significant at the 90% level and some forests have fewer large fires in the warm phase of PDO. The tendency for warm phase of PDO to increase the likelihood of large fires holds when the results are aggregated for all forests. Some forests do not show the same sensitivity

Table 2. Correlations Between Pacific Decadal Oscillation and Annual Burn Area at the Scale of Selected National Forests in Washington, Oregon, and Idaho. Note that the Number of Years of Available Data Varies by National Forest; All Time Series Run to the Year 2000.

	Correlation Coefficient	No. of Years in Data Set	Significant Relationship with PDO at 95% Level?
Colville	0.284	44	Yes
Deschutes	0.195	78	Yes
Fremont	0.236	72	Yes
Gifford Pinchot	0.186	49	No
Malheur	−0.035	51	No
Baker-Snoqualmie	0.12	51	No
Mt. Hood	0.108	53	No
Nez Perce	0.304	45	Yes
Ochoco	−0.068	70	No
Okanogan	0.181	56	No
Olympic	−0.132	58	No
Rogue River	0.178	47	No
Siskiyou	0.276	63	Yes
Siuslaw	0.133	52	No
Umatilla	0.234	63	Yes
Umpqua	0.24	57	Yes
Wallowa-Whitman	0.154	54	No
Wenatchee	0.209	70	Yes
Willamette	−0.127	69	No
Winema	0.143	34	No

to the PDO that the regional average shows; as with meteorological data (Mote et al., 2003), variability exists within the overall regional patterns.

The occurrence of drought, as measured by the PDSI, during warm phases of PDO may explain the linkage between PDO and wildfire (Fig. 6). PDSI is correlated with both PDO and wildfire activity. Regional PDSI and PDO values are moderately well correlated ($P < 0.10$), and PDSI values indicating drought conditions are correlated with the BAI for Idaho ($P < 0.10$), Oregon ($P < 0.01$), and Washington ($P < 0.01$).

El Niño/Southern Oscillation

At the regional scale, the 20th century forest fire data for the PNW show little relationship to ENSO. We found no statistically significant relationship

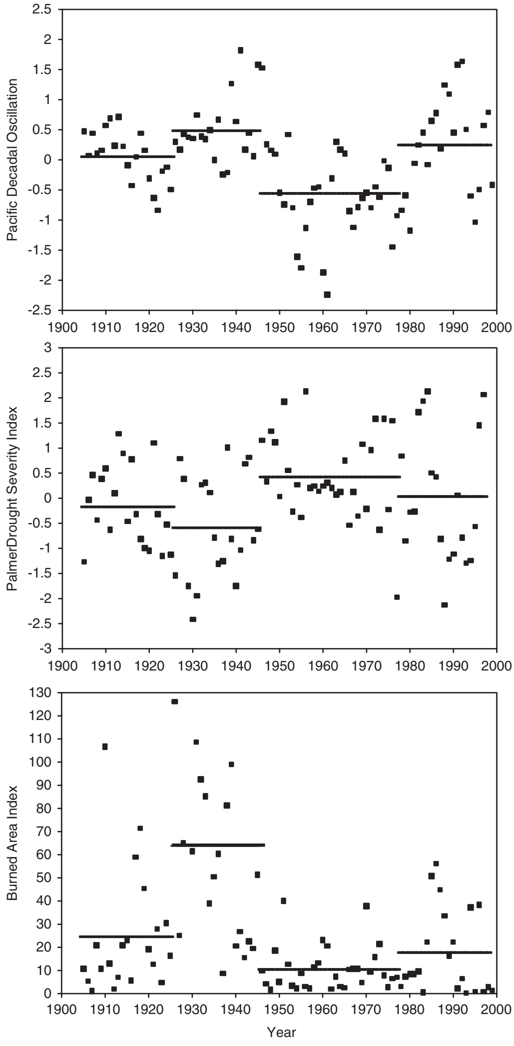

Fig. 6. Top: The Winter Pacific Decadal Oscillation (PDO) Index and Its Mean for each Phase Shift over the 20th Century. Positive values of the PDO are indicative of its warm/dry phase, whereas negative values are typical during cool/wet phases. Middle: The winter Palmer Drought Severity Index (PDSI) and its mean during each phase of the PDO. Negative values of the PDSI are indicative of drought conditions. Bottom: Burn Area Index for Washington and Oregon (USDA Forest Service Region 6) and its mean during phases of the PDO. Note the correspondence in means (lines) for each of the three indexes.

between the two. However, there may nevertheless be an indirect relationship through drought mechanisms. The PDSI is influenced by ENSO ($R = -0.48$, $P < 0.05$), and in turn the PDSI is a fairly good predictor of how extensive wildfires will be in a given year.

Relationships between ENSO and BAI were variable at the state level. ENSO was not correlated with BAI for Oregon and Washington; the variables were moderately well correlated for Idaho ($P < 0.10$). At the scale of national forests, statistically significant correlations between BAI and warm phases of ENSO were found for only 5 of the 20 national forests analyzed. These were the Deschutes ($R = 0.27$, $P < 0.01$), the Fremont ($R = 0.36$, $P < 0.001$), the Rogue, the Siskiyou ($R = 0.17$, $P < 0.1$), and the Winema ($R = 0.32$, $P < 0.01$).

DISCUSSION

Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) influences forest fire activity at multiple spatial scales in the PNW based on our analysis. These relationships are variable at within-region scales. Warm-dry phases of PDO are particularly influential in terms of the occurrence of very large fire events throughout the PNW. It is noteworthy that summer PDO was not correlated with BAI, probably because it has too little influence over summer climate in the PNW. Winter PDO, by comparison, has a large influence on snowpack and thus, indirectly, on summer soil moisture availability in montane systems.

All of the national forests positively correlated with warm-phase PDO were in portions of the PNW characterized by lower precipitation (compared to coastal forests) and dry coniferous forests at low to moderate elevations. Fire in these forest systems/sub-regions appears to show greater sensitivity to PDO. Linkages between fire occurrence and PDO have been reported for the interior Northwest by previous studies based on analysis of tree ring records (Hessl et al., 2004; Heyerdahl, Brubaker, & Agee, 2001). For instance, atmospheric circulation patterns from May to August appear to have influenced the area burned by wildlife in interior forests for several centuries prior to the advent of fire suppression (Gedalof, Peterson, & Mantua, 2005). Our results suggest that the influence of PDO on annual burn area and sub-regional variation in fire activity is evident in the historic record as well.

Before 20th century fire trends can be attributed to climate variability there are other confounding influences that warrant consideration. Some of the decline in the area burned by wildfires during the cool phase of PDO after 1945 and some of the increase in the most recent warm phase may be related to effects of fire suppression programs. Fire suppression retarded fire activity beginning mid-century, leading to elevated fire hazards in the later 20th century as fuel loads, tree densities, and in-growth of fire-prone species increased. Although these changes were prevalent primarily in dry, interior Northwest forests (Quigley, Haynes, & Graham, 1996) they may have created a confounding trend relative to PDO. However, that our results are nevertheless robust is suggested by historic precipitation and streamflow data (Mote et al., 1999a) which show that the 1925–1945 period was unusually dry in the Columbia River Basin. That period also had the largest amount of fire activity during the 20th century. Moreover, PDO and BAI are correlated when considering inter-annual oscillations in both indexes, suggesting a relationship that is apparent even when superimposed on inter-decadal trends.

El Niño/Southern Oscillation

Our analysis at the regional-scale showed no statistically significant correlations between 20th century area burned and ENSO, despite the connection between ENSO and PDSI, and variable relationships at smaller scales. Given the strong relationship between ENSO and burned area in the U.S. Southwest (Swetnam & Betancourt, 1990), and the strong statistical relationship between ENSO and climate in the Northwest, this result was unexpected, although previous studies have also found an ‘‘ambiguous relationship between ENSO and fire occurrence’’ in portions of the Northwest (Hessl et al., 2004). We suggest two possible explanations for our results. First, ENSO has a strong effect on the Southwest's rainfall, which often leads to greater fuel accumulations during positive phases of ENSO. As a consequence, late-summer fires tend to increase during and after a cool wet El Niño winter. In contrast, high fuel loadings are always present in temperate forests west of the Cascade Range and in those forest types characterized by a multi-storied structure in the interior Northwest. Thus, sub-regional variations in climate–fire relations may be obscured when fire activity is averaged at the regional level. Second, 20th century fire suppression may have obscured climate–fire relationships on inter-annual time scales (Hessl et al., 2004; Westerling & Swetnam, 2003).

There is reason to suspect linkages between ENSO and wildfire at smaller geographic scales. Some watersheds in the Blue Mountains of northeastern Oregon and southeastern Washington show a statistical relationship between annual extent of low-severity fires and El Niño events; others do not (Heyerdahl et al., 2001; Heyerdahl, Brubaker, & Agee, 2002). Positive correlations were attributed to ENSO modulation of snowpack formation. It is interesting also to consider the ecological characteristics of the five national forests where we found burn area to be correlated with warm/dry phases of ENSO. All five forests are characterized by low to moderate severity fire regimes, with precipitation regimes among the driest and most drought-prone in the region. However, several national forests with similar characteristics did not show correlations between burn area and ENSO.

Tree-ring studies, using pre-fire suppression fire data, have proven more effective at exploring linkages between ENSO and forest fires. This research has found a strong polarity between the Southwest and Northwest United States in drought responses to ENSO (Westerling & Swetnam, 2003). El Niño (ENSO negative) events tend to be hot and dry in the Northwest vs. cool and wet in the Southwest; the inverse is true of La Niña (ENSO positive) events. It has also found indications of increased forest fires in the Northwest during El Niño years, especially if there is a sequence of multiple El Niño (hot/dry) years, during which fuels become successively more desiccated. There are interactions between ENSO and PDO: fire activity is highest during the coincidence of hot/dry phases of both climate patterns (Westerling & Swetnam, 2003).

Drought as an Intermediary Mechanism

Our results are consistent with other studies establishing drought as a mechanism linking climate variability, especially PDO, with fire activity in the Northwest (Hessl et al., 2004; McKenzie et al., 2004; Westerling & Swetnam, 2003). We found the PDSI to be an intermediary variable correlated with both 20th century climate variability and burn area. This is consistent with our understanding of drought-related disturbance dynamics. Reduced tree vigor during drought years makes trees more susceptible to both insect attack and wildfire damage (Swetnam & Lynch, 1993). Fire hazards are predicted using PDSI because the index is predictive of fuel conditions, such as fuel moisture content and flammability, in general (Westerling & Swetnam, 2003).

Drought appears to have had an important influence on fire occurrence for several hundred years in the interior Columbia Basin (Hessl et al., 2004) and U.S. Southwest (Westerling & Swetnam, 2003) prior to the advent of fire suppression. In dry, interior Northwest forests there may have been interactions between periods of higher moisture that increased fuel production, followed by drought years that created conditions necessary for fire ignition and spread. Major fire events in forests west of the Cascade Range also coincided with prolonged periods of drought during the last 1,000 years, based on fire history reconstructions (Hemstrom & Franklin, 1982). Thus, drought is, both statistically and biophysically, a primary mechanism linking climate variability and wildfire activity.

Synoptic-Scale Fire Weather

There are limitations in our ability to link climate variability with fire activity and predict future risks associated with climate change. Indicative of this uncertainty is that the historic fire data are "noisy;" substantial fire activity occurs across both cool-wet and warm-dry phases of PDO. This signals the critical importance of fire weather that may be unrelated to larger modes of climate variability, such as PDO. In particular, there are synoptic-scale (on the order of 2000 km) weather events that are strongly associated with fire outbreak and spread. These "fire weather" sequences occur even during otherwise wet years and weaken the connection between years with many large fires and seasonal-scale climate variations like those associated with ENSO and PDO.

A number of studies have described a synoptic-scale sequence of weather events leading to lightning-caused ignition and fire spread. This sequence of weather events has been described for boreal forests in Canada (Johnson & Wowchuk, 1993; Jones, 2000), coastal temperate coniferous forests in the PNW (Huff & Agee, 1980; Pickford, Fahnestock, & Ottmar, 1980), ponderosa pine forests in the Southwest (Swetnam & Betancourt, 1990), and for the entire United States by sub-region (Heilman, Eenigenberg, & Main, 1994). For the PNW, the weather sequence begins with the development of an atmospheric high-pressure upper-level ridge, also known as a blocking high-pressure system. The high-pressure system may last a month or more, during which time precipitation and humidity are low, temperatures are high, and winds are light. These conditions leave fuels dry and vegetation severely stressed. When the high-pressure system partially or fully breaks down, convective storms can lead to lightning-caused ignition which, when combined with higher wind speeds, can lead to fire spread through the now flammable fuels (Lenihan, Daly, Bachelet, & Neilson, 1998). Other work also points to the importance of dry, east winds (Agee & Flewelling, 1983) and specific surface airflow systems with offshore components that lead to fire weather (Heilman et al., 1994; Schroeder et al., 1962).

Potential Effects of 21st Century Climate Change on Fire Regimes

Even moderate (e.g., $\pm 0.3°C$ decadal mean) fluctuations in PNW climate over the 20th century have influenced wildfire activity based on our analysis. Similar trends have been reported for other regions of the western U.S. (Westerling & Swetnam, 2003). Forest fire activity has been sensitive to climate variability, even in the face of altered dynamics due to fire suppression as in the case of our analysis using historic data. It is likely, therefore, that fire activity will increase over the next century in response to future temperature increases, at the same or greater magnitude as experienced during past climate variability. Forest fire activity in the western U.S., and in the northern Rocky Mountain region especially, may already have increased since the mid 1980s in response to warming and earlier spring snowmelt (Westerling, Hidalgo, Cayan, & Swetnam, 2006).

While some General Circulation Model (GCM) produced climate scenarios (e.g., Hadley Centre) predict increases in precipitation for the PNW over the next century, this is unlikely to offset wildfire risks because net summer soil moisture is also predicted to decrease (Keeton et al., in press). This is apparent in analyses integrating potential changes in temperature and precipitation. One such exercise used the MAPSS-Century vegetation change model (Neilson & Drapek, 1998), which includes a fire component. This model has been run using the HADCM2 and CGCM1 climate scenarios at monthly time steps from 1895 to 2100. Under both scenarios, the biomass consumed by fire in the PNW increases markedly by the middle of the 21st century (Bachelet, Neilson, Lenihan, & Drapek, 2001).

Ultimately, whether or not fire hazards increase will depend on changes in the intensity and duration of extreme fire weather; McKenzie et al. (2004) suggest that these will increase across the western U.S. in response to climate change. If the extreme drought conditions become more prevalent we can expect a greater frequency of large, high-intensity forest fires based on our results and previous research (Brown et al., 2004; Westerling & Swetnam, 2003). Increases in forest fire activity may be particularly pronounced in drought-prone portions of the interior PNW. In interior forests, increased fuel production outside of summer, caused, for instance, by the increased spring and fall precipitation predicted by some climate models, could exacerbate wildfire risks associated with summer drought.

There is a rapidly emerging consensus that western wildlife risks, in both wildland areas and along the suburban–wildland interface, will increase substantially over the next century. Our predictions based on climate projections (Mote et al., 2003) are supported by studies that have simulated wildfire activity under altered climatic conditions (Brown et al., 2004; McKenzie et al., 2004; Price & Rind, 1994). Predictions of increased fire frequency, intensity, and extent under a doubled CO_2 climate are consistent across a range of regions, including the northern Rocky Mountains (Gardner, Hargrove, Turner, & Romme, 1996; Romme & Turner, 1991), temperate and boreal forests in Canada (Flannigan & Van Wagner, 1991), and northern California (Torn & Fried, 1992). Altered fire regimes are likely to cause related changes in both forest structure and species distribution patterns (Fosberg et al., 1992; McKenzie, Peterson, & Alvarado, 1996).

It is important to note that there are uncertainties in predictions of increased fire frequency and intensity with warmer, drier conditions (Agee, 1993). These include the difficulty of predicting potential changes in other important factors that influence fire activity, such as wind direction, synoptic-scale sequences of weather, and lightning activity (Agee, 1993; Agee & Flewelling, 1983). Uncertainties regarding lightning, however, may be overshadowed by the fact that the vast majority of fires in the Northwest are human caused; we found that over 80% of forest fires were human caused during the 20th century. The dynamics of natural ignition sources are thus unlikely to limit fire activity. If human ignition sources remain dominant and fire susceptibilities increase, fire activity will change regardless of lightning activity. It is uncertain whether societal changes, such as cultural, educational, or technological changes, might reduce or elevate future risks related to human caused ignitions.

Potentially elevated fire risks associated with climate change are compounded by the increased fire hazards created by 20th century fire exclusion in lower elevation forests of the interior Northwest (see Chapter 5 by Menning in this volume for further information on the history and consequences of fire suppression). In forests that once supported low to moderate severity fire regimes, fire suppression, logging, and grazing have increased susceptibilities to fire, insects, and pathogens by increasing stand densities and associated drought stress and by decreasing landscape heterogeneity (Hessburg, Mitchell, & Filip, 1994; Lehmkuhl, Hessburg, Everett, Huff, & Ottmar, 1994; Swetnam, Wickman, Paul, & Baisan, 1995). Consequently, climate changes leading to increased frequency and intensity of summer drought could exacerbate the already elevated susceptibility of some interior Northwest forests to disturbances, particularly in dry forest types at lower elevations.

Climate change has additional implications for positive feedbacks between fire and other disturbances, such as synergistic interactions between fire and insect outbreaks. For example, outbreaks of bark beetles and other cambium-feeding insects are sometimes triggered by fires that weaken or kill trees (Agee, 1993; Hessburg et al., 1994). Similarly, increased frequency and intensity of insect attacks increase dead and dying fuel loads and associated fire hazards. Increased drought frequency would perturb physiological mechanisms involved in these feedback relationships, such as production of defensive compounds by trees. Multiple climate change-related stresses have the potential to create feedback loops that reinforce trajectories of change in disturbance regimes and related alterations of ecosystem structure and function.

Implications for the Urban–Wildland Interface

Predicted climate change impacts on forest fire hazards in the western U.S. raise a red flag for those engaged in fire management planning within the urban–wildland interface. Suburban or "exurban" (Theobald, 2005) expansion into partially or fully forested areas in fire-prone regions brings people and property into direct conflict with systems where fire is both natural and frequent (see Chapter 4 by Paterson in this volume for more information on fire-safe planning in interface communities). These threats have become far more pronounced in recent decades (Cova et al., 2004; GAO, 1999). For example, from 1980 to 2000 the area of suburban and exurban development increased by 133, 143, 117, and 124% for Idaho, Montana, Oregon, and Washington, respectively (Theobald, 2003a). In drier, fire-prone areas, suburban developments and scattered dwellings already face elevated fire risks due to the effects of past fire suppression. Increased vulnerability to forest fires over coming decades caused by climate change may worsen the current fire management problem. It is highly likely that this situation will become increasingly prevalent over the next century (Brown et al., 2004; Mote et al., 2003), necessitating further adaptation of both suburban development planning and allocation of fire management and restoration resources.

Forest managers are struggling to find politically acceptable, ecological sound, and financially expedient solutions to the current fire hazards, for instance through prioritized fuels treatment and fire restoration projects. The goal typically is to restore forest stand and landscape-level characteristics associated with historic fire regimes. When these projects involve thinning forest stands or prescribed burning, support from local residents can vary widely (Brown et al., 2004; Pyne, Andrew, & Laven, 1996; Sagoff, 2004). For instance, the potential for prescribed fires to generate large volumes of smoke and associated reductions in air quality sometimes leads to public opposition (see Chapter 5 by Menning in this volume for further description of the social and regulatory constraints to prescribed burning). Fire restoration planning and implementation are highly contentious on federal lands, especially when they involve high levels of timber harvest and forest management in recreational or roadless areas. Forest managers must weigh sometimes competing management objectives: areas prioritized for fuels treatment do not always coincide with degree of threat to communities. For example, the fall 2003 fires that burned more than 774,000 acres in southern California (Fig. 7) were located primarily on non-federal lands (68%) and in non-forest vegetation (78%) according to an analysis conducted by The Wilderness Society (2003). Yet proposed federal fire

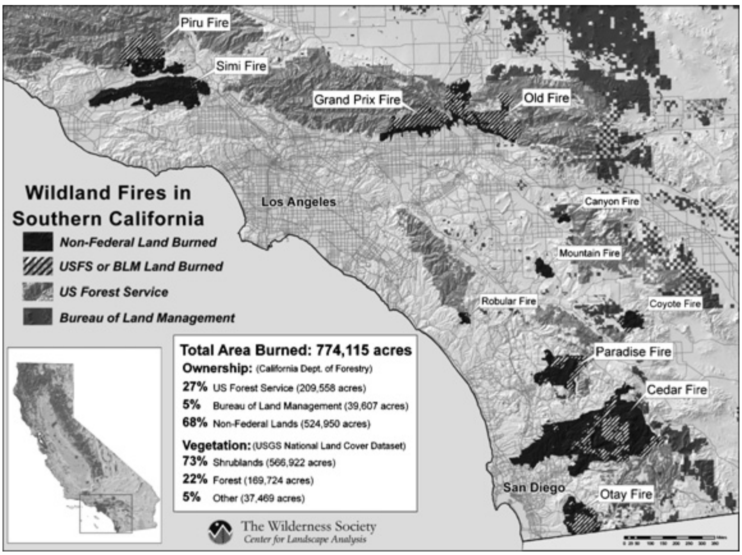

Fig. 7. Extent of the 2003 Wildfires in Southern California. Figure is reprinted with permission from The Wilderness Society (2003).

restoration projects target primarily federal lands, representing only 32%, and the more remote, forested periphery, of the burn area (The Wilderness Society, 2003). If fire-related threats to human safety and property increase as a result of climate change, fire restoration planning would need to be modified accordingly. For instance, with limited resources available, the location of projects may need to be prioritized based on: (a) degree of threat to human safety and property (e.g., proximity to semi-developed areas); and (b) landscape-level fire containment strategies, such as creation of fuel breaks and defensive zones.

Fire suppression in the U.S. currently costs over $1.6 billion in annual expenditures (Whitlock, 2004), and may be as high as $2 billion on average (Brown et al., 2004). Because hotter temperatures in the future will expand the duration of fire seasons (McKenzie et al., 2004), cautionary "no burn" periods, vegetation clearing around buildings, and maintenance of reserve fire fighting capacity will need to be extended as well. Between 1980 and 2000, 90% of fire suppression costs were accounted for by the most expensive 20% of fires exceeding 40 hectares (Brown et al., 2004). Consider that our results, as well as previous research (McKenzie et al., 2004), suggest that extreme fire weather is the dominant driver of fire vulnerability at regional scales. McKenzie et al. (2004) suggest that extreme fire weather will become more prevalent with climatic changes. This is likely to increase the intensity, or energy release component (ERC, a measure integrating precipitation and relative humidity and representing weather conditions as per the National Fire Danger Rating System), of future fires (Brown et al., 2004). The time period of ERC values above 60 (a threshold correlated with large fires) is predicted to increase by two weeks by 2070 across the western U.S., with the exception of Colorado, Montana, and Wyoming, where little or no change of this type is predicted (Brown et al., 2004). Hotter fires in the future will thus increase suppression and containment costs, disproportionately. Within the urban–wildland or exurban–wildland interface these costs may be even higher, relative to undeveloped areas, because of the need to protect human safety and property (Keeley, 2002).

The number of fires and area burned increases as population density increases (Keeley, Fotheringham, & Morais, 1999); we have found that the vast majority of fires during the 20th century in the PNW were human caused rather than ignited by lightning (Keeton et al., In press). Thus, if climate variability enhances conditions for fire spread, for instance through staggered periods of increased fuel production followed by drought (Brown et al., 2004; Keeton et al., In press; McKenzie et al., 2004; Swetnam & Betancourt, 1990), it is likely that the frequency and extent of uncontrolled, human-caused fires will also increase in areas with human habitation and activity. For example, the increased occurrence of chaparral fires in southern California appears to be directly related to expanding human populations – and thus human-caused ignitions – rather than fire suppression or fuel loads (Keeley, 2002). While the dry, autumn Santa Anna or "foëhn" winds are the primary cause of large, spreading shrubland fires in southern California (Keeley et al., 1999), susceptibility to wind-driven fires is predicted to increase with climate change in this region if drought conditions worsen (Torn & Fried, 1992). Thus, shrubland fire activity in southern California will reflect interactions between climate change effects and human-caused ignitions. Shorter fire-return intervals in savanna, shrubland, and chaparral systems enhance opportunities for the spread of weedy or annual species, including exotic species. This creates positive feedbacks with fire that contribute to the displacement of native species (various citations in McKenzie et al., 2004).

Adaptation of fire management and planning will be essential to address fire hazards in the urban–wildland interface as the climate changes. Development patterns in much of the U.S. have shifted fundamentally from what, in the past, might have been a clearly discernable expansion along an "urban–wildland interface" to what has become a mixed-use pattern of dispersed dwellings within a matrix of undeveloped vegetation (Brown et al., 2005; Theobald, 2005). This greatly complicates both fire restoration and fire fighting. In some cases public opposition (Sagoff, 2004) and fragmented ownership patterns make strategic planning of fuel breaks and buffer zones more challenging. During large fire outbreaks, fire fighting resources and public safety personnel must be reallocated to protect human life and property.

A comprehensive strategy to address this situation will require many elements (see, for example, Cohen & Saveland, 1997; Keeley, 2002; Lavin, 1997; Summerfelt, 2002); we will make three key recommendations. First, managers should consider focusing efforts on the strategic placement of fire restoration (Hardy & Arno, 1996; Raymond & Peterson, 2005) and fuel profile modification projects (i.e. "fuel breaks") within and around the urban–wildland interface, to the extent this can be delineated given exurban development (see Chapter 3 by Stephens & Collins in this volume for a further description of urban–wildland interface zone fire containment strategies). The potentially negative effects of these projects, such as habitat fragmentation and vectoring of non-native species (Merriam, Keeley, & Beyers, 2006), also need to be considered carefully in determining where and if fuel breaks are desirable. Fire restoration should emphasize the urban–wildland interface rather than previously unmanaged backcountry because: (a) this approach may be more cost effective (Canton-Thompson et al., 2006); and (b) higher-elevation forest types and unroaded backcountry are the least likely to have been affected by fire suppression (Bessie & Johnson, 1995; Quigley et al., 1996). Areas should be prioritized for treatment based on landscape-scale planning in this manner. Prioritization should consider possible fire behavior and spread, for instance using fire behavior models where applicable and feasible given input data requirements (see, for example, Scott & Burgan, 2005). It should also include pre-fire planning of fire-fighting strategies and tactics, personnel deployments, and evacuation routes (Rhode, 2004). Increased allocation of resources to this type of activity may prove more cost-effective and ecologically sound in terms of: (a) limiting the spread of fires; (b) protecting human property; and (c) restoring natural fire dynamics and ecosystem characteristics associated with historic disturbance regimes. Central to these efforts will be long-term planning in anticipation of future forest ecosystem change. This would require a significant change in forest management to consider climate information, which, based on our surveys of forest managers (Keeton et al., In press; Mote et al., 2003), is rarely considered.

Our second recommendation is to make better use of climate forecasts. Our current ability is limited to short-term predictions of fire weather. But improved understanding of PDO and ENSO will improve fire management planning with forecasted fire conditions anticipated over months to perhaps one or more years in advance (McKenzie et al., 2004). As relationships between variables used in current fire hazard prediction, such as the National Fire Danger Rating System, and modes of climatic variability are better documented, it will be possible to connect, in an increasingly sophisticated manner, fire prediction with climatic forecasts.

Finally, it is essential that communities carefully consider the consequences of continued residential expansion into fire-prone forested and shrubland areas. Apart from ecological concerns associated with sprawl and habitat fragmentation, risks from fire to property can represent an enormous financial burden on local communities, both in terms of insurance, pre-fire damage prevention, fire fighting, and repair following fires (Summerfelt, 2002; Truesdale (1995)). Climate change presents additional risks in terms of the potential for increased costs and threats in the urban–wildland interface. Growth management planning and open space conservation offer tools to minimize these impacts (Theobald, 2003b). These may prove especially fruitful if climate change affects forest fire regimes as we have predicted.

REFERENCES

Agee, J. K. (1993). *Fire ecology of Pacific Northwest forests*. Washington DC: Island Press.

Agee, J. K., & Flewelling, R. (1983). A fire cycle model based on climate for the Olympic Mountains, Washington. *Proceedings of the Fire and Meteorology Conference*, *7*, 32–37.

Allen, C.D., & Breshears, D.D. (1998). Drought-induced shift of a forest-woodland ecotone: Rapid landscape response to climate variation. *Proceedings of the National Academy of Sciences*, 95, 14,839–14,842. National Academy of Sciences, Washington, D.C.

Bachelet, D., Neilson, R. P., Lenihan, J. M., & Drapek, R. J. (2001). Climate change effects on vegetation distribution and carbon budget in the United States. *Ecosystems*, *4*, 164–185.

Bessie, W. C., & Johnson, E. A. (1995). The relative importance of fuels and weather on fire behavior in subalpine forests. *Ecology*, *76*, 747–762.

Bretherton, C. S., Widmann, M., Dymnikov, V. P., Wallace, J. M., & Blade, I. (1999). Effective number of degrees of freedom of a spatial field. *Journal of Climate*, *12*, 1990–2009.

Brown, D. G., Johnson, K. M., Loveland, T. R., & Theobald, D. M. (2005). Rural land use trends in the conterminous U.S., 1950–2000. *Ecological Applications*, *15*, 1851–1863.

Brown, T. J., Hall, B. L., & Westerling, A. (2004). The impact of twenty-first century climate change on wildland fire danger in the western United States: An applications perspective. *Climatic Change*, *62*, 365–388.

Brubaker, L. B. (1986). Responses of tree populations to climatic change. *Vegetatio*, *67*, 119–130.

Brubaker, L. B. (1988). Vegetation history and anticipating future change. In: J. K. Agee & D. Johnson (Eds), *Ecosystem management for parks and wilderness* (pp. 41–60). Seattle, Washington: University of Washington Press.

Canton-Thompson, J., Thompson, B., Gebert, K., Calkin, D., Donovan, G., & Jones, G. (2006). *Factors affecting fire suppression costs as identified by incident management teams*. USDA Forest Service Research Note RMRS-RN-30.

Cohen, J., & Saveland, J. (1997). Structure ignition assessment can help reduce fire damages in the W-UI. *Fire Management Today*, *57*(4), 19–23.

Cova, T. J., Sutton, P., & Theobald, D. M. (2004). Exurban change detection in fire-prone areas with nighttime satellite imagery. *Photogrammetric Engineering & Remote Sensing*, *70*, 1249–1257.

Dale, V. H., & Franklin, J. F. (1989). Potential effects of climate change on stand development in the Pacific Northwest. *Canadian Journal of Forest Resources*, *19*, 1581–1590.

Flannigan, M. D., & Van Wagner, C. E. (1991). Climate change and wildfire in Canada. *Canadian Journal of Forest Research*, *21*, 66–72.

Fosberg, M. A., Mearns, L. O., & Price, C. (1992). Climate change- fire interactions at the global scale: Predictions and limitations of methods. In: P. J. Crutzen & J. G. Goldammer (Eds), *Fire in the Environment* (Ch 8). New York: Wiley and Sons.

Franklin, J. F., Spies, T. A., Van Pelt, R., Carey, A., Thornburgh, D., Berg, D. R., Lindenmayer, D., Harmon, M., Keeton, W. S., Shaw, D. C., Bible, K., & Chen, J. (2002). Disturbances and the structural development of natural forest ecosystems with some implications for silviculture. *Forest Ecology and Management*, *155*, 399–423.

Franklin, J. F., Swanson, F. J., Harmon, M. E., Perry, D. A., Spies, T. A., Dale, V. H., McKee, A., Ferrell, W. K., Means, J. E., Gregory, S. V., Lattin, J. D., Schowalter, T. D., & Larsen, D. (1991). Effects of global climatic change on forests in northwestern North America. *Northwest Environmental Journal*, *7*, 233–254.

Gardner, R. H., Hargrove, W. W., Turner, M. G., & Romme, W. H. (1996). Climate change, disturbances, and landscape dynamics. In: B. Walker & W. Steffen (Eds), *Global change and terrestrial ecosystems* (pp. 149–172). Cambridge, UK: Cambridge University Press.

Gedalof, Z., & Smith, D. J. (2001). Interdecadal climate variability and regime-scale shifts in Pacific North America. *Geophysical Research Letters*, *28*, 1515–1518.

Gedalof, Z. M., Peterson, D. L., & Mantua, N. J. (2005). Atmospheric, climatic and ecological controls on extreme wildfire years in the northwestern United States. *Ecological Applications*, *15*, 154–174.

Hardy, C. C., & Arno, S. F. (eds). (1996). *The use of fire in fire restoration.* USDA Forest Service General Technical Report InT-GTR-341.

Heilman, W. E., Eenigenberg, J. E., & Main, W. A. (1994). Upper-air synoptic patterns associated with regional fire-weather episodes. In: *Proceedings of the 12th Conference on Fire and Forest Meteorology* (pp. 355–370). Publication 94-02. Society of American Foresters, Bethesda, MD.

Hemstrom, M. A., & Franklin, J. F. (1982). Fire and other recent disturbances in Mount Rainier National Park. *Quaternary Research*, *18*, 32–51.

Hessburg, P. F., Mitchell, R. G., & Filip, G. M. (1994). *Eastside forest ecosystem health assessment: Historical and current roles of insects and pathogens in eastern Oregon and Washington forested landscapes,* Vol. 3. USDA Forest Service General Technical Report PNW-GTR-327.

Hessl, A. E., McKenzie, D., & Schellhaas, R. (2004). Drought and Pacific Decadal Oscillation linked to fire occurrence in the inland Pacific Northwest. *Ecological Applications*, *14*, 425–442.

Heyerdahl, E., Brubaker, L. B., & Agee, J. K. (2001). Spatial controls of historical fire regimes: A multiscale example from the interior west, USA. *Ecology*, *82*, 660–678.

Heyerdahl, E., Brubaker, L. B., & Agee, J. K. (2002). Annual and decadal climate forcing of historical fire regimes in the interior Pacific Northwest, USA. *The Holocene*, *12*, 597–604.

Huff, M. A., & Agee, J. K. (1980). Characteristics of large lightning fires in the Olympic Mountains, Washington. In: *Proceedings of the Sixth Conference of Fire and Forest Meteorology* (pp. 117–123). Society of American Foresters, Washington DC.

Intergovernmental Panel on Climate Change (IPCC). (2001). *Climate Change 2001: Synthesis Report.* IPCC, Geneva, Switzerland. pp. 184.

Johnson, E. A., & Wowchuk, D. R. (1993). Wildfires in the southern Canadian Rocky Mountains and their relationship to mid-tropospheric anomalies. *Canadian Journal of Forest Research*, *23*, 1213–1222.

Jones, J. A. (2000). Hydrologic processes and peak discharge response to forest harvest, regrowth, and roads in ten small experimental basins, western Cascades, Oregon. *Water Resources Research*, *36*, 2621–2642.

Keeton, W. S., Franklin, J. F., & Mote, P. W. (in press). Climate variability, climate change, and forest ecosystems in the Pacific Northwest. In: E. L. Miles, A. K. Snover, and The Climate Impacts Group (Eds), *Rhythms of change: An integrated assessment of climate impacts on the Pacific Northwest* (Chapter 8). Boston: MIT Press.

Keeley, J. E. (2002). Fire management of California shrubland landscapes. *Environmental Management*, *29*, 395–408.

Keeley, J. E., Fotheringham, C. J., & Morais, M. (1999). Reexamining fire suppression impacts on brushland fire regimes. *Science*, *284*, 1829–1832.

Lavin, M. J. (1997). Managing risk to people, structures, and the environment. *Fire Management Today*, *57*, 4–6.

Lehmkuhl, J. J., Hessburg, P. F., Everett, R. L., Huff, M. H., & Ottmar, R. D. (1994). *Historical and current forest landscapes of eastern Oregon and Washington.* USDA Forest Service General Technical Report PNW-GTR-328.

Lenihan, J. M., Daly, C., Bachelet, D., & Neilson, R. P. (1998). Simulating broad-scale fire severity in a dynamic global vegetation model. *Northwest Science*, *72*, 91–103.

Mantua, N. J., Hare, S. R., Zhang, Y., Wallace, J. M., & Francis, R. C. (1997). A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society*, *78*, 1069–1079.

McPhaden, M. J., et al. (1998). The tropical ocean-global atmosphere observing system: A decade of progress. *Journal of Geophysical Research*, *103*, 14169–14240.

McKenzie, D., Gedalof, Z., Peterson, D. L., & Mote, P. (2004). Climatic change, wildfire, and conservation. *Conservation Biology*, *18*, 890–902.

McKenzie, D., Peterson, D. L., & Alvarado, E. (1996). *Predicting the effect of fire on large-scale vegetation patterns in North America.* USDA Forest Service Research Paper PNW-489.

Merriam, K. E., Keeley, J. E., & Beyers, J. L. (2006). Fuel breaks affect nonnative species abundance in Californian plant communities. *Ecological Applications*, *16*, 515–527.

Mote, P. W., Canning, D. J., Fluharty, D. L., Francis, R. C., Franklin, J. F., Hamlet, A. F., Hershman, M., Holmberg, M., Ideker, K. N., Keeton, W. S., Lettenmaier, D. P., Leung, L. R., Mantua, N. J., Miles, E. L., Noble, B., Parandvash, H., Peterson, D. W., Snover, A. K., & Willard, S. R. (1999a). *Impacts of Climate Variability and Change, Pacific Northwest.* National Atmospheric and Oceanic Administration, Office of Global Programs, and JISAO/SMA Climate Impacts Group, Seattle, WA. 110 pp.

Mote, P. W., Keeton, W. S., & Franklin, J. F. (1999b). Decadal variations in forest fire activity in the Pacific Northwest. In: *Proceedings of the eleventh conference on Applied Climatology* (pp. 155–156). American Meteorological Society, Boston, MA.

Mote, P. W., Parson, E. A., Hamlet, A. F., Ideker, K. N., Keeton, W. S., Lettenmaier, D. P., Mantua, N. J., Miles, E. L., Peterson, D. W., Peterson, D. L., Slaughter, R., & Snover, A. K. (2003). Preparing for climate change: The water, salmon, and forests of the Pacific Northwest. *Climatic Change*, *61*, 45–88.

National Assessment Synthesis Team (NAST). (2000). *Climate change impacts on the United States: The potential consequences of climate variability and change*. New York: Cambridge University Press.

Neilson, R. P., & Drapek, R. J. (1998). Potentially complex biosphere responses to transient global warming. *Global Change Biology*, *4*, 101–117.

Overpeck, J. T., Rind, D., & Goldberg, R. (1990). Climate-induced changes in forest disturbance and vegetation. *Nature*, *343*, 51–53.

Palmer, W. C. (1965). *Meteorological drought.* Research Paper No. 45, U.S. Department of Commerce Weather Bureau, Washington DC.

Parson, E. A., Mote, P. W., Hamlet, A., Mantua, N., Snover, A., Keeton, W. S., Miles, E., Canning, D., & Gray Ideker, K. (2001). Potential impacts of climate variability and change on the Pacific Northwest. In: National Assessment Synthesis Team (Eds), *Climate change impacts on the United States: The potential consequences of climate variability and change* (Chapter 9). New York: Cambridge University Press.

Pickford, S. G., Fahnestock, G. R., & Ottmar, R. (1980). Weather, fuels, and lightning fires in Olympic National Park. *Northwest Science*, *54*, 92–105.

Price, C., & Rind, D. (1994). The impact of a 2xCO_2 climate on lightning-caused fires. *Journal of Climate*, *7*, 1484–1495.

Pyne, S.J., Andrew, P.J., Laven, R.D. (1996). *Introduction to wildland fire* (2nd ed., p. 769). New York: John Wiley and Sons.

Quigley, T., Haynes, M., R. W., & Graham, R. T. (1996). *Integrated scientific assessment for ecosystem management in the interior Columbia Basin.* USDA Forest Service General Technical Report PNW-382. U.S.

Raymond, C. L., & Peterson, D. L. (2005). Fuel treatments alter the effects of wildfire in a mixed-evergreen forest, Oregon, USA. *Canadian Journal of Forest Research*, *35*, 2981–2995.

Rhode, M. S. (2004). Fires in the wildland/urban interface: Best command practices. *Fire Management Today*, *64*(2), 27–31.

Romme, W. H., & Turner, M. G. (1991). Implications of global climate change for biogeographic patterns in the greater Yellowstone ecosystem. *Conservation Biology*, *5*, 373–386.

Ryan, K. C. (1991). Vegetation and wildland fire: Implications of global climate change. *Environment International*, *17*, 169–178.

Sagoff, M. (2004). *Price, principle, and the environment*. Cambridge, UK: Cambridge University Press pp. 294.

Schroeder, M. J., Glovinsky, M., Hendricks, V. F., Hood, F. C., Hull, M. K., Jacobson, H. L., Kirkpatrick, R., Krueger, D. W., Mallory, L. P., Oertel, A. G., Reese, R. H., Sergius, L. A., & Syverson, C. E. (1962). *Synoptic weather types associated with critical fire weather*. Prepared by the U.S. Department of Commerce, Weather Bureau, and the U.S. Department of Agriculture, Forest Service for the Office of Civil Defense, Office of the Secretary of the Army. U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

Scott, J. H., & Burgan, R. E. (2005). *Standard fire behavior fuel models: A comprehensive set for use with Rothermel's SurfaceFire Spread Model*. USDA Forest Service General Technical Report RMRS-GTR-153.

Summerfelt, P. (2002). The wildland/urban interface: What's really at risk? *Fire Management Today*, *63*(1), 4–8.

Swetnam, T. W., & Betancourt, J. L. (1990). Fire-Southern Oscillation relations in the southwestern U.S. *Science*, *249*, 1017–1020.

Swetnam, T. W., & Lynch, A. M. (1993). Multicentury, regional-scale patterns of western spruce budworm outbreaks. *Ecological Monographs*, *63*, 399–424.

Swetnam, T. W., Wickman, B. E., Paul, H. G., & Baisan, C. H. (1995). *Historical patterns of Western Spruce Budworm and Douglas-Fir tussock moth outbreaks in the Northern Blue Mountains, Oregon, since AD 1700*. USDA Forest Service Research Paper PNW-RP-484.

Theobald, D. (2005). Landscape patterns of exurban growth in the USA from 1980 to 2020. *Ecology and Society*, *10*, 32.

Theobald, D. M. (2003a). *Defining and mapping rural sprawl: Examples from the Northwest US*. Growth Management Leadership Alliance white paper. 16 September 2003.

Theobald, D. M. (2003b). Targeting conservation action through assessment of protection and exurban threats. *Conservation Biology*, *17*, 1624–1637.

The Wilderness Society. (2003). *Mapping analysis: The healthy forests initiative and the southern California fires*. Ecology and Economics Research Department, Science and Policy Brief November 2003, No. 12.

Torn, M. S., & Fried, J. S. (1992). Predicting the impacts of global warming on wildland fire. *Climate Change*, *21*, 257–274.

Truesdale, D. (1995). Fire suppression costs on large fires: a review of the 1994 fire season. *Fire and Aviation Management* 8.

United States General Accounting Office (GAO). (1999). Western National Forests: Nearby communities are increasingly threatened by catastrophic fires. GAO/T-RCED-99-79.

Westerling, A., Hidalgo, H., Cayan, D., & Swetnam, T. (2006). Warming and earlier spring increase western US forest wildfire activity. *Science*, *313*, 940–943.

Westerling, A. L., & Swetnam, T. W. (2003). Interannual to decadal drought and wildfire in the Western United States. *EOS*, *84*, 545–560.

Whitlock, C. (2004). Forests, fire, and climate. *Nature*, *432*, 28–29.

Zar, J. H. (1996). *Biostatistical Analysis* (3rd ed). Upper Saddle River, NJ: Prentice Hall.

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